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Evolution of Large, Organic Debris After Timber Harvest: Maybeso Creek, 1949 to 1978

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ABSTRACT

The Maybeso Creek valley was logged from 1953 to 1960. Stream maps showing large accumulations of debris and stream channel features were made in 1949 and updated to 1960. The objectives of this paper are to document the effects of natural and logging debris on channel morphometry and to examine the fate of logging debris during and after logging. Map sections from 1949 through 1963 are examined and compared with a ground survey in 1978 of debris accumulations.

Natural conditions before logging revealed sparse accumulations of large debris scattered throughout the stream; these accumulations increased in number and density during logging. Natural material appeared to be well controlled and stable; whereas, logging debris was floatable. Year-to-year changes in accumulations were noted throughout the period of logging from 1953 to 1969. Fewer accumulations were observed in 1978 than in 1949, before the start of logging. Further studies are needed to quantify physical changes and to relate these changes to salmon habitat.

KEYWORDS: Logging (-erosion, erosion-) forestry methods, sedimentation, morphometry.

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INTRODUCTION

Most undisturbed stream systems in southeast Alaska flow through predominantly old-growth spruce-hemlock forests. During the natural course of events, these systems are exposed to organic inputs, ranging from needles to material the size of trees. In the past, timber harvest has left substantial amounts of additional organic debris in stream channels.

In this paper I discuss the role of large debris (tree boles and root wads) in the morphological changes in Maybeso Creek, Prince of Wales Island, Alaska. My objectives are to:

1. Document the general changes in morphometry of the stream channel as a result of accumulations of natural and logging debris.
2. Examine the fate of natural accumulations of large debris during and after timber harvest.
3. Discuss the influence of accumulations of natural and logging debris on stability of streams.

The role of large, organic debris in stream channel morphometry in southeast Alaska has not been well documented, but early work on Maybeso Creek provides some baseline information. James (1956) reported some early observations of debris accumulations and their effect on the stream channel in Maybeso Creek. He discussed the role of large debris in creating pools and providing cover for adult salmon.

Bishop and Shapley (1963) created a series of artificial debris jams in Maybeso Creek to examine changes in channel morphometry. Scouring occurred under and around jams, accompanied by downstream deposition of bedload. A flat riffle with an unstable streambed was created after the jam washed out during floods in the autumn. Their work was further reported by Helmers (1966), who concluded that jams increased instability during floods and produced streambed cutting. He found a decrease in fine sediments following washout.

The most recent studies of the role of large, organic debris in streams in the Cascade Ranges of western Oregon show that large debris slows water movement and traps and stores fine, organic material (Swanson and Lienkaemper 1978, Swanson et al. 1976). Large debris can be a stabilizing or destabilizing agent in stream channels, depending on the amount and placement in the stream. The greatest adverse environmental effect of large debris is from debris torrents that completely flush out small, steep streams in western Oregon.

Froehlich (1975) discussed some methods of measuring the quantity of organic debris and the differences in debris loading resulting from different logging systems. In addition, he cited windfall, insect infestations, and wildfire in several areas in Oregon as natural causes of catastrophic inputs of large debris that would otherwise accumulate at a slower rate from natural tree mortality.

From these studies it is apparent that as large pieces of debris enter a channel, gravel streambeds are scoured and banks may be eroded as stream water flows around, under, or over the block. Stable debris can form relatively long-lived bed and bank features by controlling flows. Channel instability increases with increased movement of debris.

Helmers (1966) cited the potential for reduction of fines through increased movement of gravel as a possible benefit for overwinter survival of salmon eggs and embryos. Both Helmers (1966) and Hall and Baker (1975) pointed out the detrimental effects of debris-induced scour during incubation and the mortality of embryos resulting from movement of log jams during floods.

Biological and physical effects of large debris in streams were discussed by Narver (1971) and Hall and Baker (1975). They cited examples of improved habitat when accumulations of large debris increased cover in both rearing habitat and overwintering areas for juvenile coho salmon (Oncorhynchus kisutch).

Although several reports cited debris jams as blocks to passage of fish (Merrell 1951, Howell et al. 1965), many jams do not block fish passage. Narver (1971) pointed out that log jams block fish passage when gravel is dammed behind the block, creating falls. In most circumstances, streams develop channels under or around a jam. Natural accumulations with relatively low concentrations of logs are unlikely to result in a blocking jam.

DESCRIPTION OF THE STUDY AREA

Maybeso Creek is located near Hollis on Prince of Wales Island, approximately 67 km (42 mi) west of Ketchikan, Alaska (fig. 1). The main stem of Maybeso Creek is approximately 8.3 km (5 mi) long and drains about 42 km^2 (16 mi^2) of a U-shaped valley. Mean summer discharge is approximately 2 407 liters/s (85 ft^3/s). Discharge regimes are highly variable, and fall storms frequently result in peak discharges in excess of 22 656 liters/s (800 ft^3/s) (James 1956).

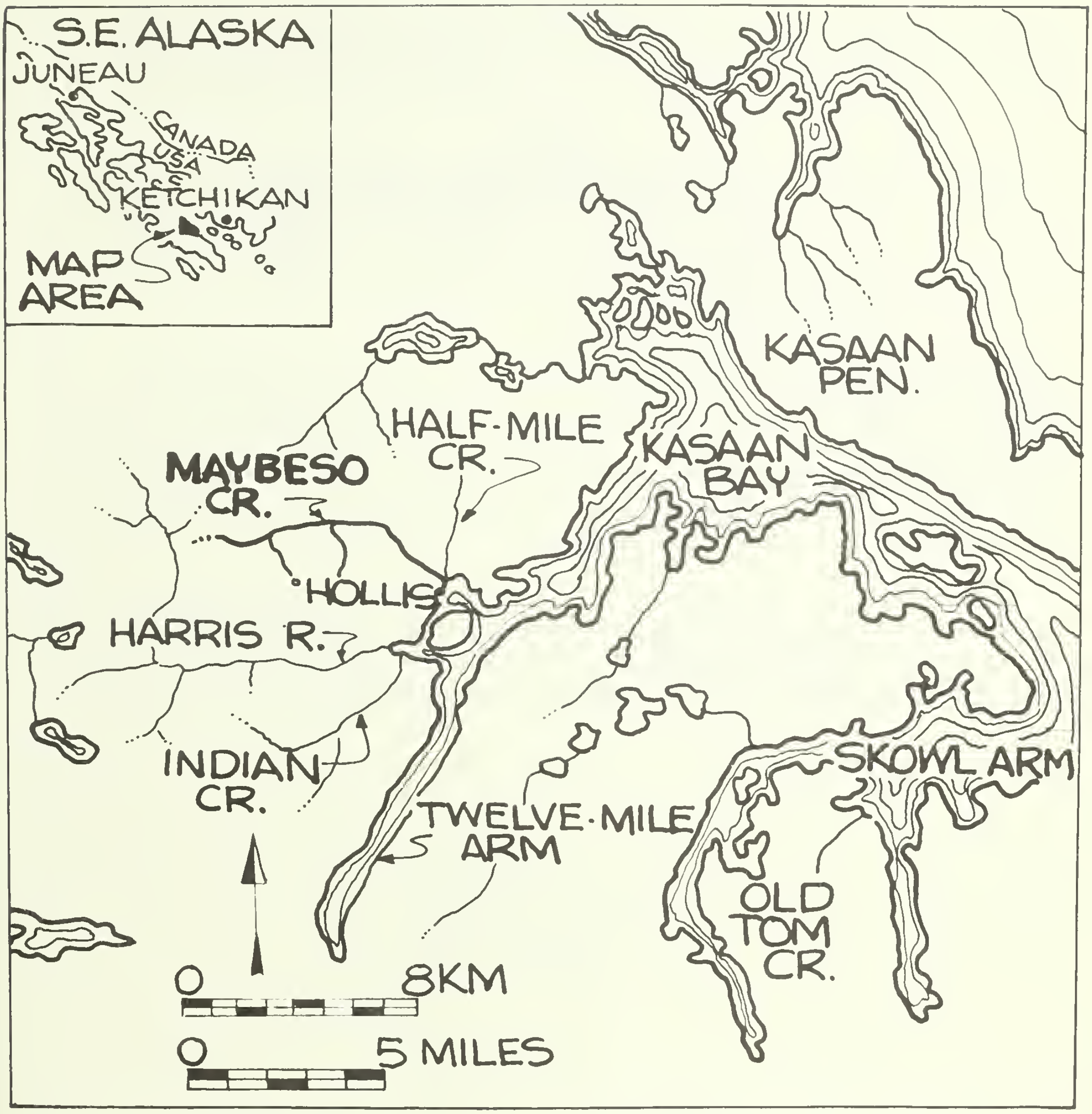


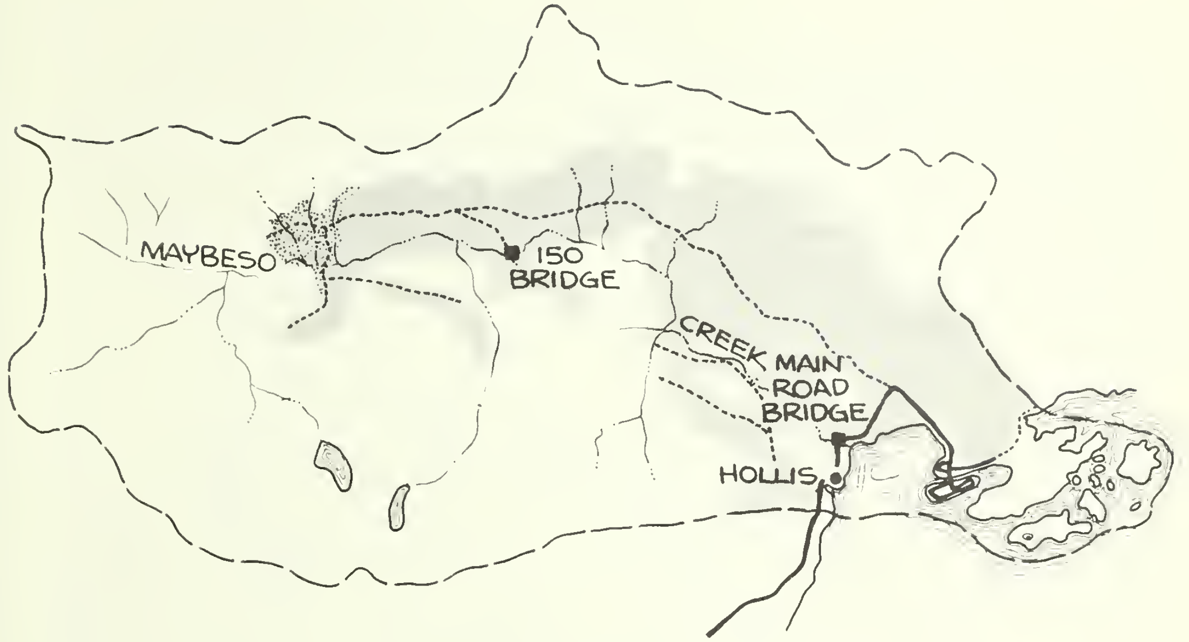
Figure 1.--Location of Maybeso Creek, Prince of Wales Island.

Early studies estimated pink (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) escapements from 0 to 2,700 (Meehan et al. 1969). Coho salmon and Dolly Varden char (*Salvelinus malma*) were observed in 1978. Cutthroat trout (*Salmo clarki*) also occur in Maybeso Creek.

Maybeso Creek from the intertidal zone to about 1 000 m (3,281 ft) upstream is heavily influenced by bedrock. Just below the present location of the main road bridge on the Hollis to Craig road (fig. 2), about 75 m (246 ft) upstream from mean high tide, the channel is constricted through bedrock, which at low flows acts as a partial block to migration of pink and chum salmon.

Logging was begun in the Maybeso Valley in 1953 and continued through 1963 (Meehan et al. 1969); nearly all merchantable timber was removed for a distance of 7.24 km (4.5 mi) along both sides of the stream (shaded area, fig. 2). A small area of large old-growth timber was left along approximately 800 m (2,625 ft) on both sides of the streambank. Remaining uncut areas along the stream were usually muskeg or small unmerchantable trees.

The dominant streamside vegetation is red alder (*Alnus rubra*), salmonberry (*Rubus spectabilis*), stink currant (*Ribes bracteosum*), and thimbleberry (*Rubus parviflorus*) interspersed with regrowth of Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*).



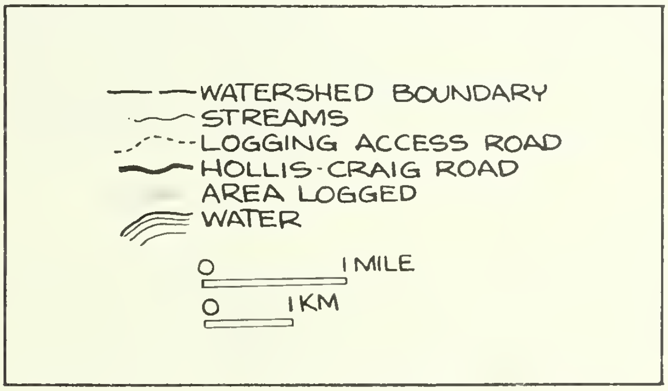


Figure 2.--Maybeso Creek watershed.

METHODS

Mapping of Maybeso Creek was started in 1949. In the following years, these maps were updated annually through 1960. The maps were drawn to 1:600 scale with a plane table and alidade and show locations of large organic debris and primary stream features, such as bedrock, gravel bars, and streamside vegetation. The map sections begin at tidewater and extend upstream approximately 5.5 km (3.4 mi).[1] As logging progressed, changes in the physical features of the stream were noted, and map sections were redrawn. Much of this paper interprets these changes and the influence of logging debris on the stream during this period.

In 1978 we walked the system with copies of the 1949 map series, the 1960 maps, and a set of aerial photographs. During this survey absence or presence of accumulations of debris were noted and comments on general stream morphometry recorded and compared with conditions shown in the map sections. Mapping was not done during this survey.

RESULTS AND DISCUSSION

1949

In the 1949 map sections, no major accumulations of debris that influenced channel morphometry appear in the first 1 000 m (3,281 ft) of Maybeso Creek. Individual pieces were interspersed along the bank and small accumulations of one or two pieces occurred at sharp bends. The first accumulation across the stream occurred at 800 m (2,625 ft). Flows followed a course under the logs; gravel bars formed around the accumulation (fig. 3). This area is influenced primarily by bedrock, indicated by the crosshatch marks on the map.

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[1]The map sections are identified by sheet numbers in figures 3-10 and figure 15. These are the numbers on the original maps, and they remain the same from year to year for each location. They are provided here for comparison with the text and also so a reader could refer to the original maps for study.

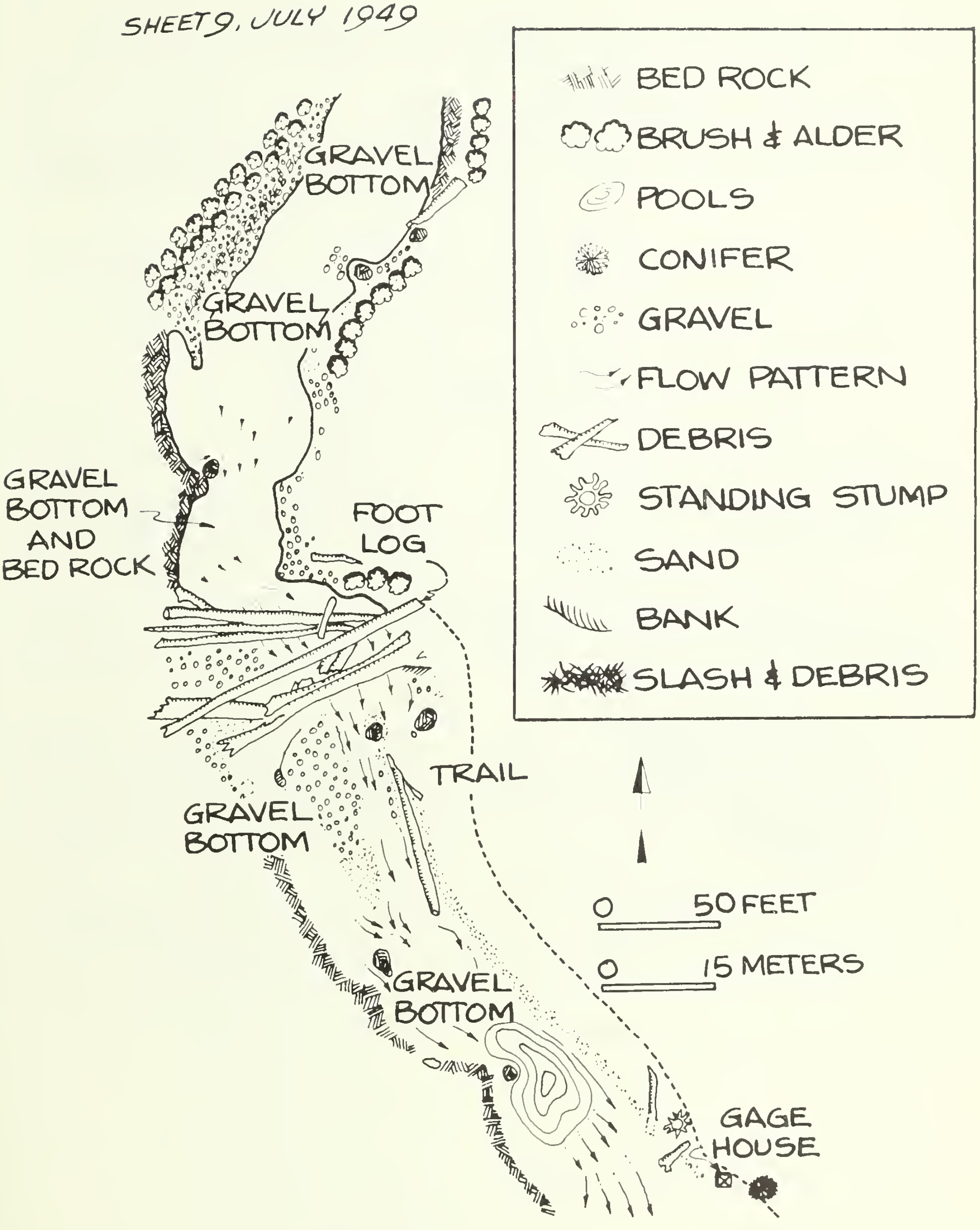

Figure 3.--Lower Maybeso Creek at the gage house, 1949.

The first accumulation of more than five logs occurred at about 1 000 m (3,281 ft) upstream (fig. 4) where eight large trees were across the stream. Although the channel was shown to flow under the log accumulation in the 1949 map, it appears that the immediate influence was to deflect the flow over what is shown in the map as a sand and gravel bar. This accumulation appears to have deflected high flows over parts of the gravel bar. A series of pools and eddies have been formed by the accumulation.

For the next several hundred meters the primary influence of debris was from fallen trees well embedded in the bank acting as deflectors and causing formation of pools and gravel bars (fig. 5). Gravel deposition and storage accompanied by pool formations occurred as debris disrupted flow. Without debris influence, the channel was scoured to bedrock with little or no gravel deposition (fig. 5).

Accumulations of debris at 2 000 m restricted flows and caused the stream to braid or create a series of islets and small channels above and around the accumulation (fig. 6). An alternating pattern of natural blowdown and open areas (figs. 4 and 5) continued upstream for most of the remaining stream sections.

Natural accumulations may begin with blowdown; these in turn erode the bank under root systems. As root systems are undercut, additional blowdown will be directed into the stream, further intensifying inputs of large debris in a restricted area (fig. 6).

Sparse natural accumulations appear to be relatively stable. Where large debris is embedded in the channel bank, year-to-year changes in the channel topography as a result of flooding and erosion decline. These accumulations tend to deflect flows and cause gravel deposition as hydraulic energy is dissipated (fig. 6). These accumulations are stable enough to allow establishment of alder on the gravel depositions. Root systems of alder may further enhance stability of gravel bars. As these areas stabilize, new material falling into the channel as a result of streambank undercutting and blowdown accumulates at a slower rate.

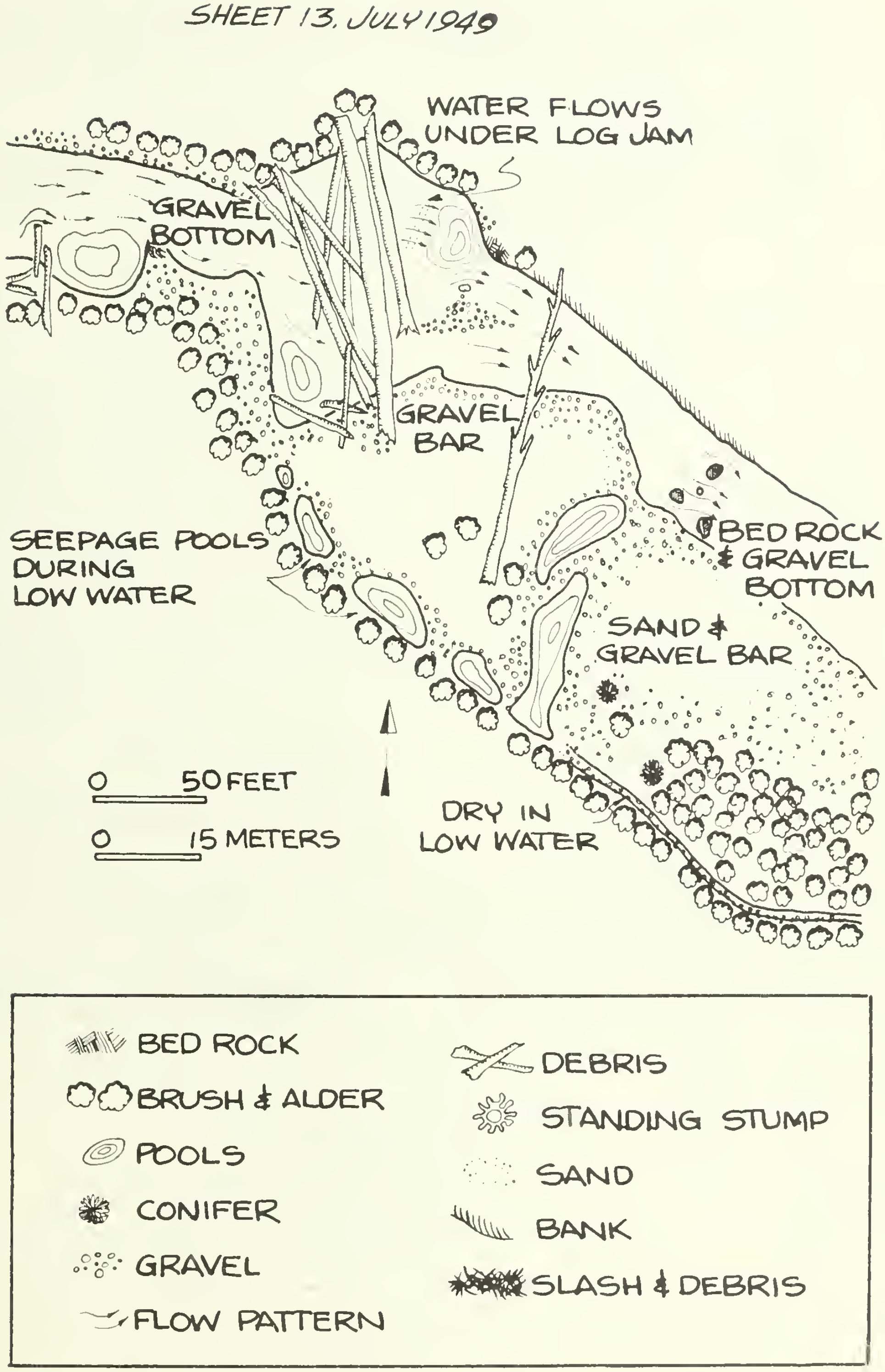

Figure 4.--Pools and eddies formed by large debris, Maybeso Creek, 1949.

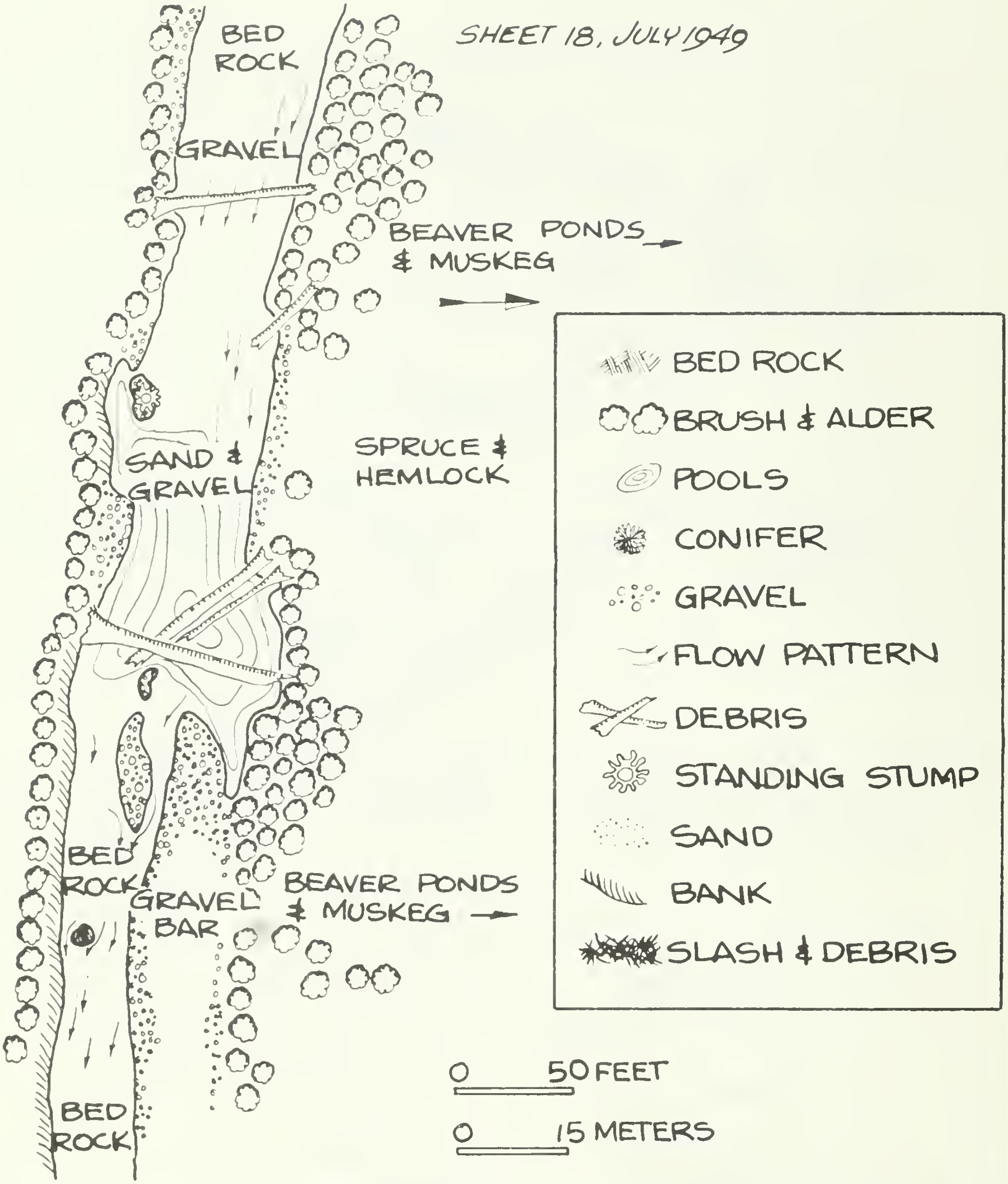

Figure 5.--Pool and gravel formation by natural input of tree-size debris. Maybeso Creek, 1949.

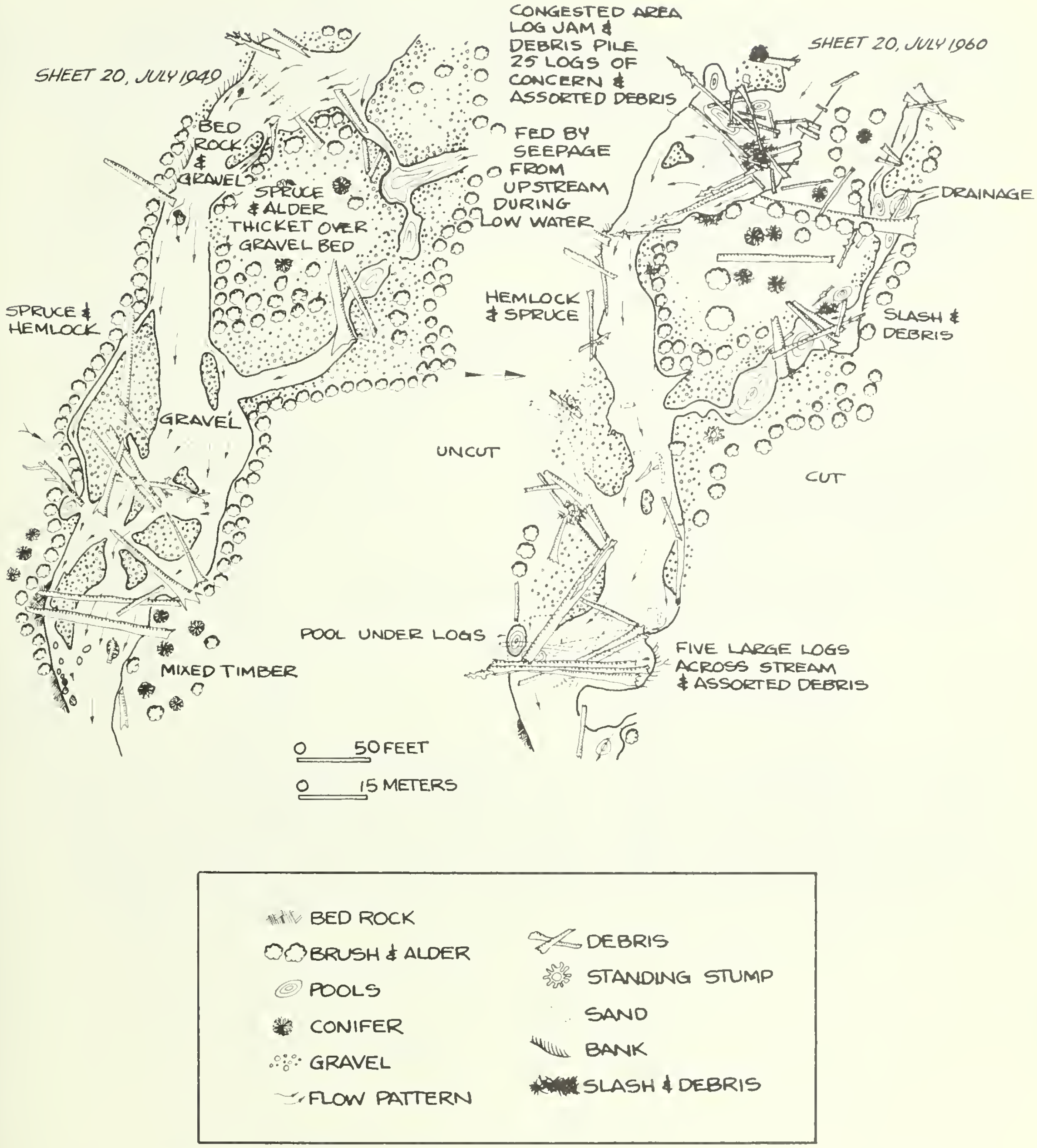

Figure 6.--Side channel and islands formed by natural inputs in 1949 and effects of heavy concentrations of logging debris in 1960.

Seventeen debris accumulations of four or more logs were counted on the 1949 maps between the main road bridge and the 150 road bridge upstream (table 1). James (1956) recorded 9 jams containing 10 or more logs 3 m (9.84 ft) or more in length in 1949 and 16 jams of 10 or more logs in 1953 immediately before logging.

Table 1--Accumulations of large debris extending across Maybeso Creek between the main road and the 150 road bridge before, during, and after logging

Year	4 or more logs	10 or more logs[1]
1949 (before logging)	17	4 (9)
1953 (during logging)	24	8 (16)
1956 (during logging	34	20
1960 (after logging)	29	21
1978 (after logging)	4	1

[1] Numbers in parentheses are from James (1956).

1960

The number and size of major accumulations of debris increased between 1953 and 1960 (table 1). The 1960 maps showed 29 accumulations of four or more logs extending across the width of the stream between the main road bridge and the 150 road bridge. A jam containing 5-10 logs in 1949 commonly included more than 20-30 logs, trees, and root wads in 1960 after logging (figs. 6 and 7).

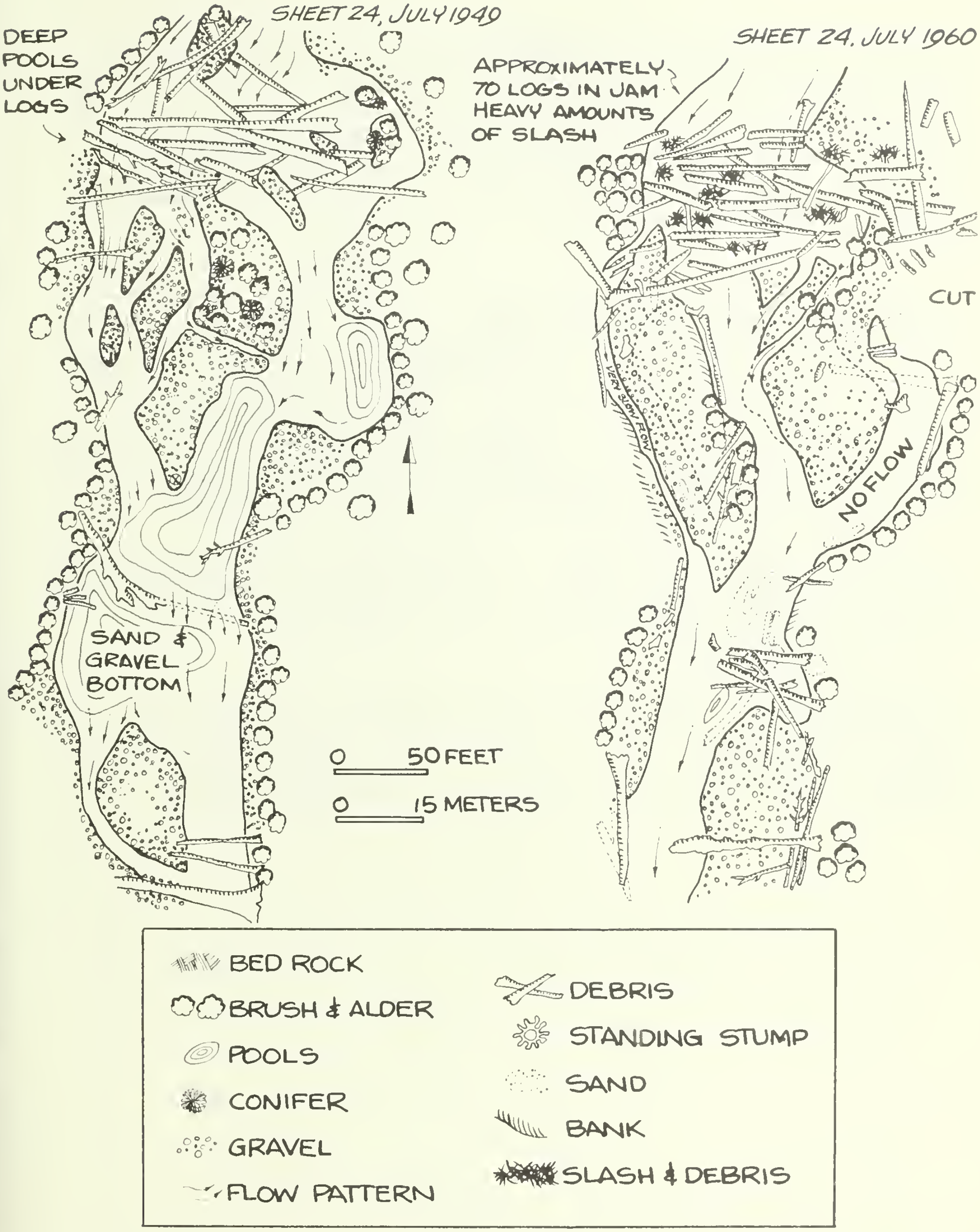

Figure 7.--Concentration of logging debris at a natural debris accumulation.

In the downstream sections, bedrock continued to be the dominant feature. No accumulations reached completely across the stream, but the number of logs and root wads projecting into the stream from the bank increased compared with 1949. Most larger accumulations in this section were probably washed out by floods and the impact of large debris moving downstream during floods. In this area, the bedrock configuration concentrates flows through a relatively restricted area and thus intensifies the effect of floods on any accumulations of debris.

Above the first 1 000 m, accumulations of large debris began to appear on the 1960 maps. Natural jams (as shown in fig. 7) frequently sieved floated debris and formed massive jams. The marginal notes on map section 24 (fig. 7) show a steady increase from 30 logs in 1955 to 70 logs in 1958. A similar situation occurred at map section 13 (fig. 4). In 1956, yarding in and around this section altered the stream drastically (fig. 8). Severe bank cutting along the north edge of the stream as a result of yarding across the stream and removal of debris in the stream caused extensive changes in the channel.

Relatively little change occurred in the upstream area where muskegs and beaver ponds border the bank. Some noticeable downstream movement of debris occurred. Comparison of the 1949 and 1960 map sections (fig. 9) showed little movement of debris or new input.

From 1949 to 1960, jams became larger and more frequent in the upstream sections. Areas with natural blowdown and braiding were completely occluded by debris as small side channels were filled with slash and heavy debris (fig. 7). As a result, the main channel was frequently rerouted and flow diverted away from side channels.

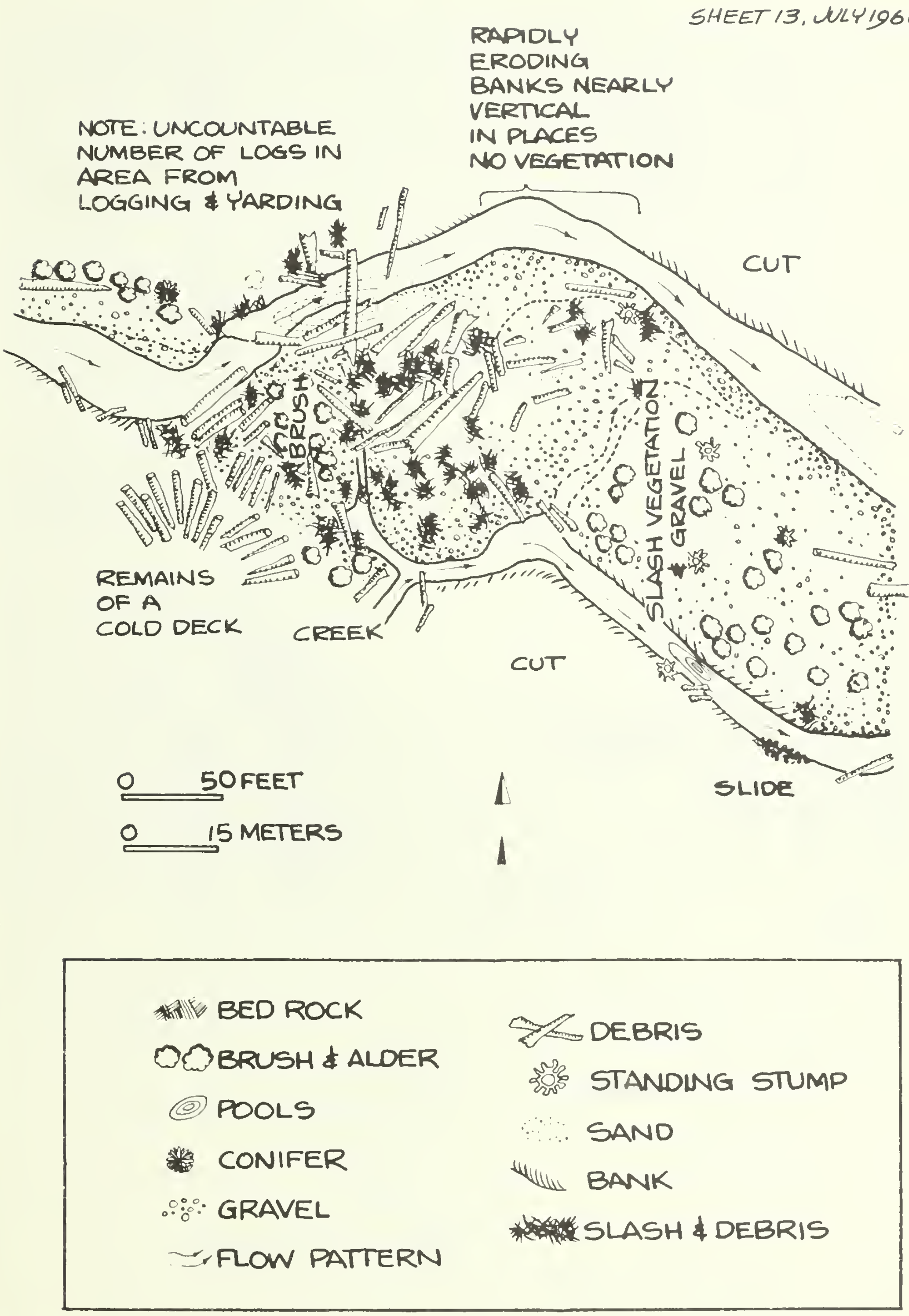

Figure 8.--Map section 13 in 1960 showing results of yarding and removal of debris in Maybeso Creek. Figure 4 shows 1949 conditions in this section.

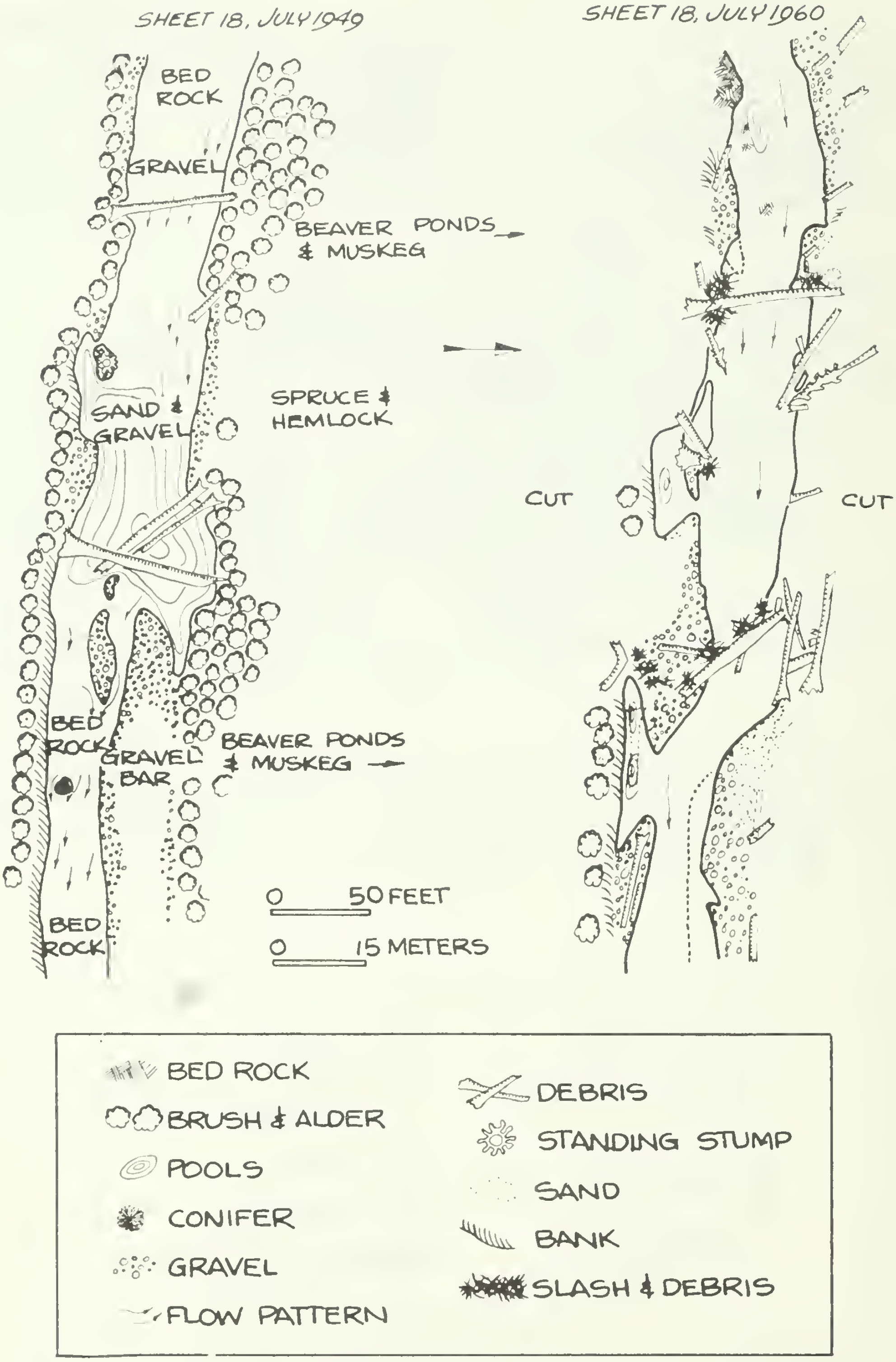

Figure 9.--Maybeso Creek, 1949 and 1960, at low levels of debris loading.

Although new jams were recorded on the 1960 maps, the largest accumulations occurred at points where natural debris had accumulated. Most new jams occurred at gravel bars. Jams generated by logging debris generally appeared to be less stable on a year-to-year basis than those created naturally. The relative instability of logging debris is illustrated by the map section series in figure 10. Logging debris began to accumulate in 1953. After the first addition of debris, the jam and channel began to gradually shift. Another channel was cut along the north bank with substantial gravel movement as flows were redirected. Over the 11-year period shown in figure 10, considerable movement occurred within the jam as individual pieces moved into and out of it. Most of the debris accumulation shown in figure 11 was floatable, large tree-size material. During fall floods, this material becomes highly mobile.

The major effects of logging debris jams were changes in the channel, bank erosion, and scour, aggravated by washout of accumulations of unstable large debris. After 1961, logging in the valley was reduced and new inputs of debris decreased accordingly.

1978

The observations are based on a personal on-the-ground reconnaissance. Because mapping was discontinued with the 1960 map series, no comparable maps were available for conditions in 1978. Copies of the 1949 and 1960 series were used as references during the reconnaissance. Where changes were observed, notes were made on the map sheets. Aerial photographs taken at various times before and after logging were also used as references.

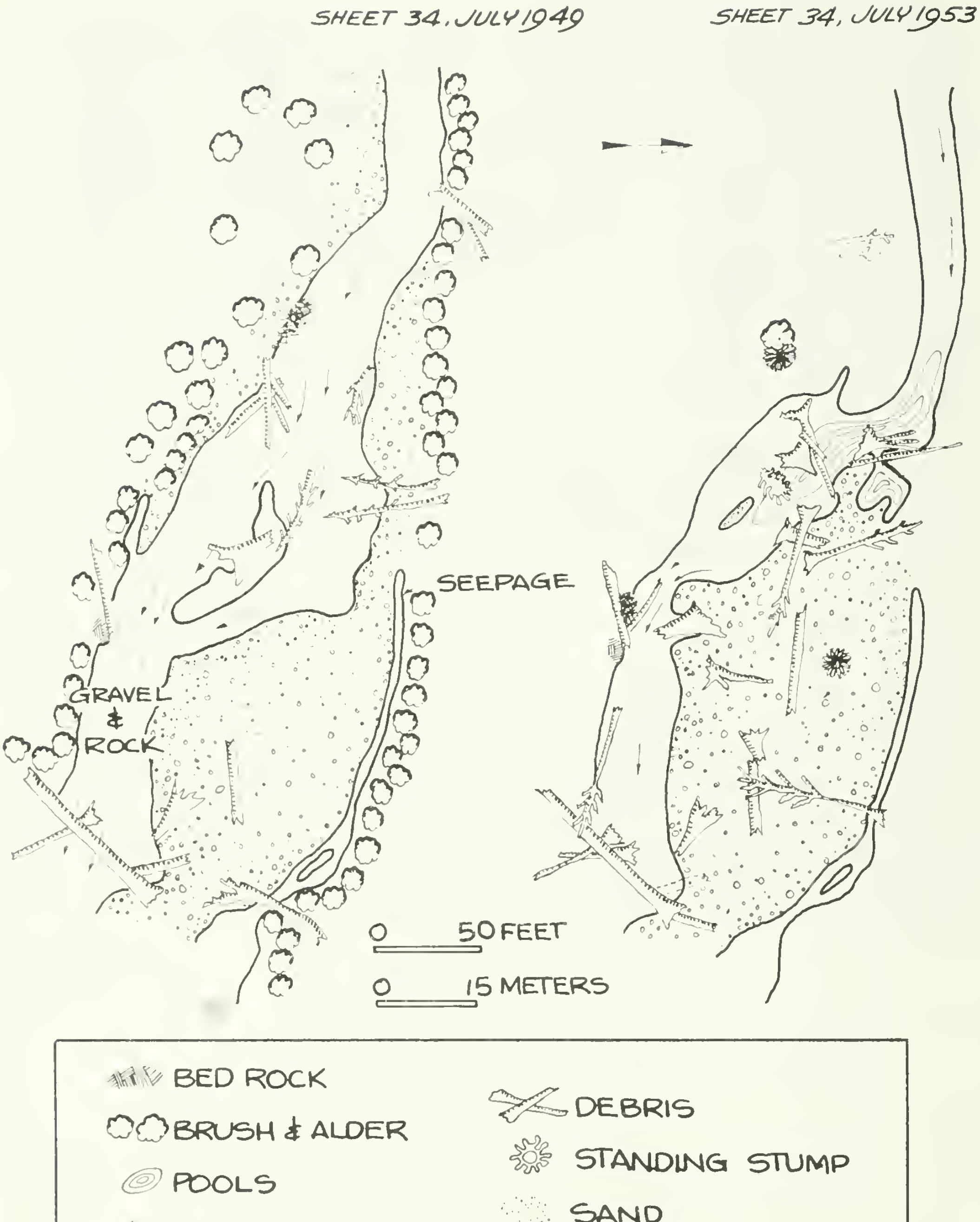

Figure 10.--Evolution of logging debris jam, 1949-60.

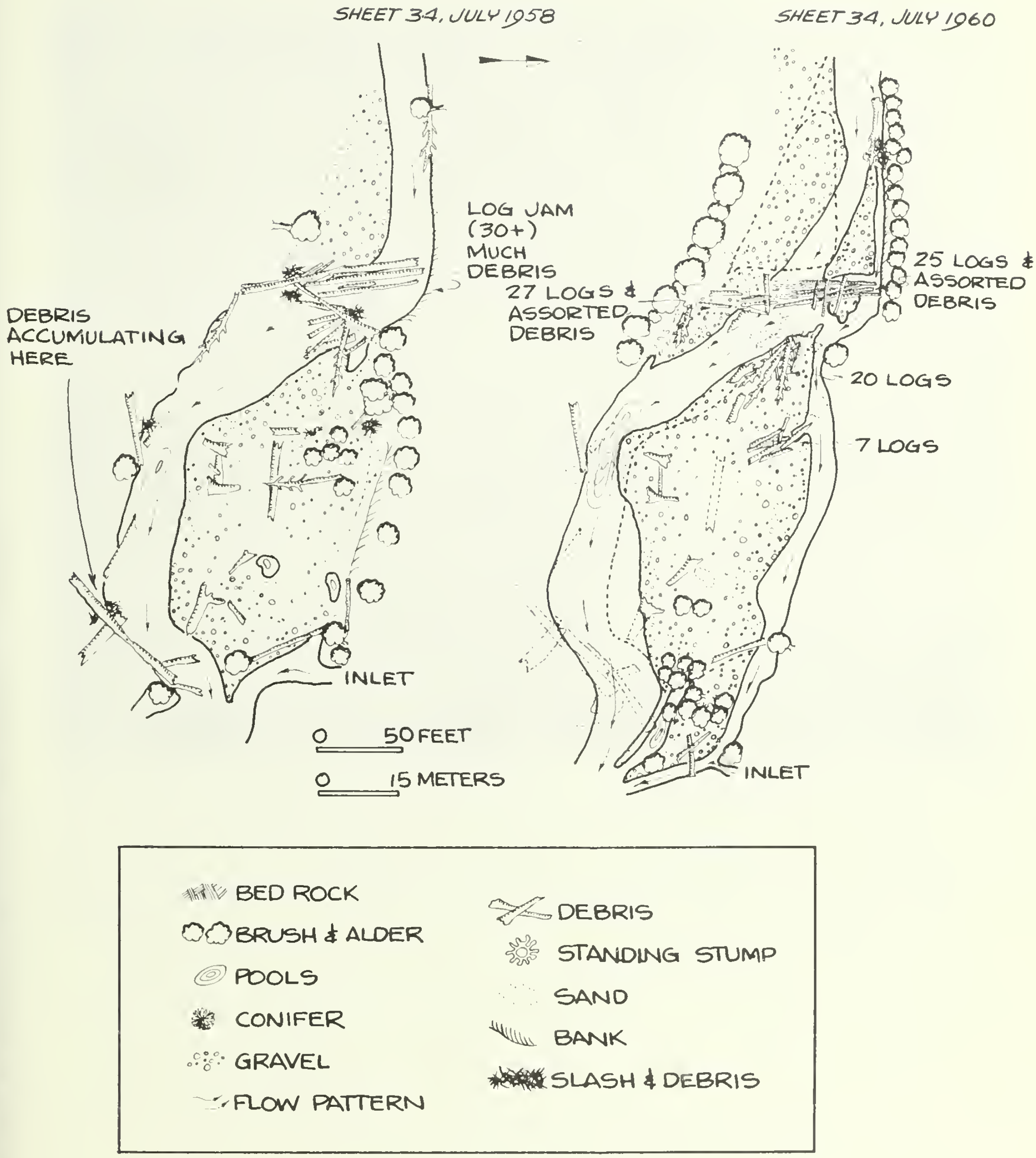

Figure 10.--Continued.


Figure 11.--Aerial photograph of map section 34, Maybeso Creek, 1961.

In 1978, many of the large debris jams shown in the 1960 map sections were absent. Furthermore, there were fewer accumulations in 1978 than in 1949 (table 1). In some places, changes were so great that it was difficult to locate ground position with either set of maps. Sections where a jam was shown in the 1960 map would commonly be replaced by a straight riffle area with overgrown banks.

Inspection of streambank areas revealed that substantial amounts of debris had been incorporated into the present bank structure. Most of this material had been thrown up on the bank during floods and was subsequently buried by flood plain deposits or regrowth of shrubs along the bank. As gravel was anchored by debris, regrowth of alder further obscured debris.

In 1978, the stream channel in the lower section was still predominantly bedrock. Accumulations of debris shown along the bank in 1960 appeared to have been either washed downstream or assimilated into the bank and flood plain. In several instances, pieces shown projecting into the stream on the 1960 map were well decayed and embedded in the bank. For the most part, there were no remarkable changes in this section.

Of the few remaining jams in 1978, all were originally natural accumulations that had increased in size as logging debris was washed downstream. Accumulations caused by logging were not evident in 1978. These appeared to have been washed out or, in some instances, may have been removed during the logging operation.

Above the first 1 000 m (3,281 ft) of stream, sparse (with respect to 1960) tree-size debris accumulations occurred on gravel bars (fig. 12). These were generally above water during low or moderate flows. They appeared to be stable and, in some cases, were partially buried. It is possible that similar pieces may be embedded beneath the gravel bars (fig. 13).

Figure 12.--Remnant accumulation of debris on a gravel bar in 1974.

Figure 13.--Gravel bank anchored by partially buried roots of a down tree.

All major concentrations of natural debris were affected by logging debris; therefore, it was difficult to directly determine residence time of accumulations of natural debris in Maybeso Creek. Trees growing on blowdowns across the Shaheen River, located north of Hollis, were aged at over 70 years in a natural accumulation of large debris.

Accumulations remaining in 1978 in Maybeso Creek appeared relatively stable. The jam shown in the 1960 map section in figure 6 appeared little changed in 1978 (fig. 14). These areas were typically characterized by deep pools with large gravel deposits above and below the accumulations. In some cases side channels were formed, but this did not appear to be as common as indicated in the 1949 map section (fig. 6). Although local movement of gravel is likely, the major pieces of debris appeared to be well embedded, and waterflow was not severely constricted.

Figure 14.--Residual accumulation in 1978. Area corresponds to jam shown in the lower section in figure 6.

Logging debris commonly destabilized existing natural accumulations of debris. As a result, many natural accumulations were either washed out or became so clogged that a new channel was formed. An example of this process is shown in figures 15 and 16. The 1949 map section shows a relatively sparse, extensive accumulation with a series of side channels and islands. In 1960 this section was completely choked with debris. By 1978 this area was rechanneled into a relatively straight riffle section shown by the dashed line in figure 15. Figure 16 shows a view of the area in 1978.

Investigation of the bank area revealed evidence of the side channels and islands. Islands were identified by patches of spruce and hemlock. Tree cores taken during the 1978 survey showed that many of these trees were at least 60 years old. Surrounding areas were overgrown by alder of various ages, but usually these were less than 25 years old. Side channels were filled with gravel. The evidence seen in this case and residence times observed elsewhere indicate that undisturbed natural accumulations, such as those seen in the 1949 map section in figure 15, are relatively stable features.

Throughout the cut areas, only negligible amounts of new debris after logging were observed. In the uncut timbered area, new blowdown was evident (fig. 17). New debris was restricted to less than 20 m of the stream length but extended completely across the channel. The effect on the stream is partly illustrated in figure 17 by the buildup of gravel in the foreground. In addition, logging debris was collecting in the jam. Individual logs from the 150 road bridge, which was located approximately 2 000 m (6,562 ft) upstream, were observed in the jam. The area around the jam appeared to be active, with bank cutting along the north side and scour under the jam. No evidence of braiding was observed.

Alder appeared to be most effective in maintaining gravel bars and gravel banks but was ineffective in cut bank areas and was easily undercut. Where active cutting occurred, alder did not appear to contribute to stability.

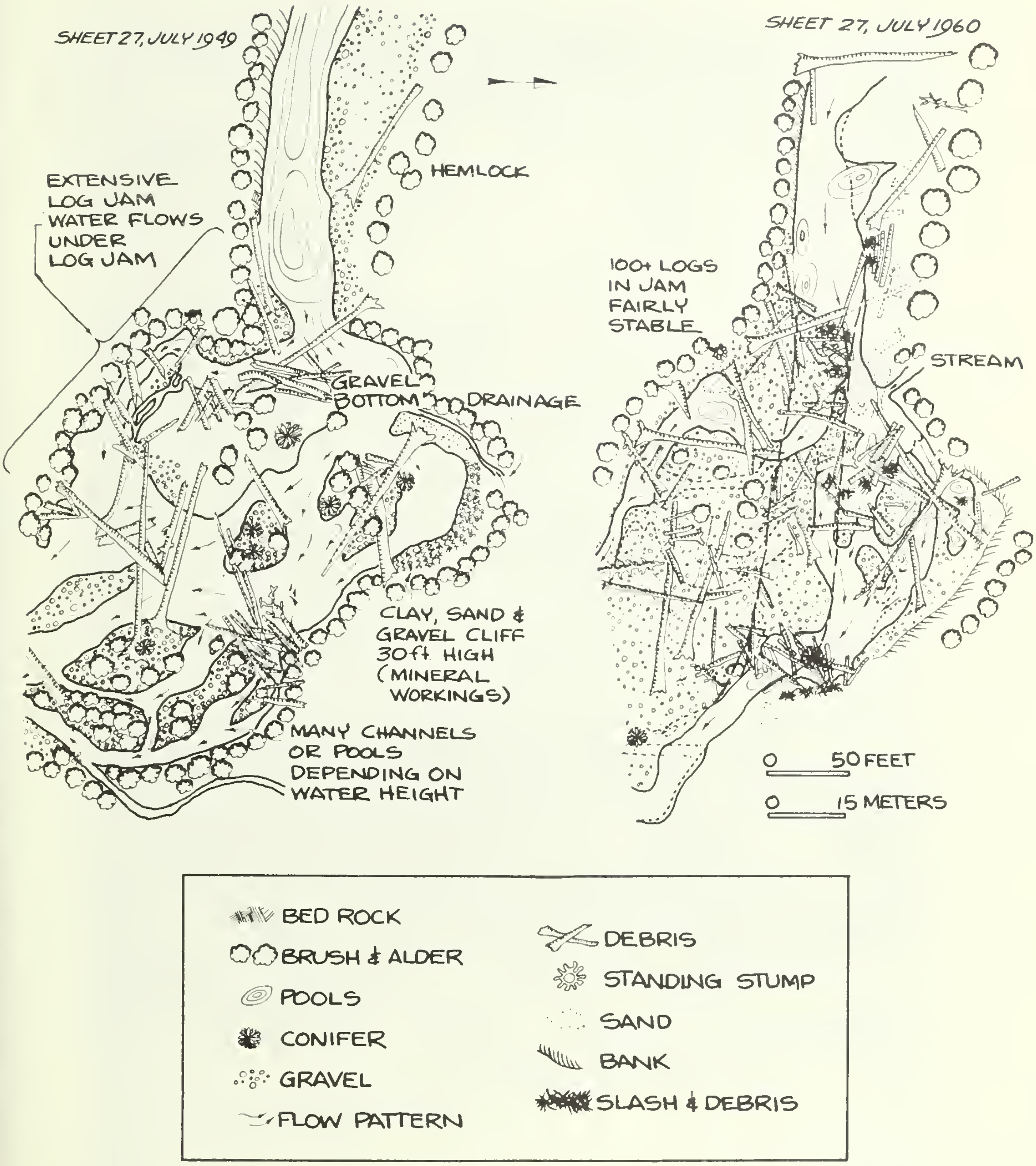

Figure 15.--Map sections of Maybeso Creek showing effects of logging debris on natural accumulation and change in channel.

Figure 16.--View from downstream into the area shown on the map sections in figure 15.

Figure 17.--Input of large debris to Maybeso Creek observed in 1978.

Figure 18 shows the primary large debris input to Maybeso Creek following logging. Bank cutting has tipped small hemlock into the stream. This material is easily floated and will not appear as a stable feature as did the large spruce and hemlock blowdown shown throughout the 1960 map sections. It is apparent that small, young hemlock and alder do not replace old-growth Sitka spruce and hemlock as a source of large debris.

Figure 18.--Illustration of streambank undercutting along Maybeso Creek in 1978.

CONCLUSIONS

Timber harvest has caused extensive changes in the stream channel of Maybeso Creek. Some of these changes may have been imposed by equipment operating in the stream, but most were related to accumulations of large debris. Natural accumulations appeared stable compared with those created by logging debris. Throughout logging, natural accumulations collected large amounts of logging debris and subsequently washed out.

The absence of old-growth forest along the streambank effectively eliminated new accumulations. The decrease in the number of accumulations of large debris after logging is apparent in table 1. As these accumulations are dissipated, pools formed around accumulations of large debris will be replaced by riffles; thus, there will be a net increase in riffle areas. As these areas stabilize, the stream channel morphology will be determined by rock formations and streambank.

It was evident that large quantities of tree-size material had been assimilated between 1960 and 1978, either within the stream or along the banks. Although amount of debris throughout the active channel has decreased, debris along the bank and projecting into the channel still plays a role in channel morphometry. In some cases, it will contribute to bank stability. These areas will also contribute to the formation of pool areas important to juvenile salmonids.

The observations of events following logging on Maybeso Creek show that accumulations of large natural debris play an active role in channel morphometry and form relatively stable features, such as pools and side channels. Natural debris accumulations are most severely affected by large floatable logging debris, whereas bedrock areas are generally unaffected.

Natural debris accumulations sieved floatable logging debris which created massive jams that became unstable and washed out. After logging, accumulations of large debris decreased in size and number. The few remaining in Maybeso Creek are remnants of old natural accumulations.

For a full understanding of the significance of these changes, additional work remains: (1) remapping the stream to provide a complete picture of the changes in channel morphometry in the last 20 years, (2) analyzing organic and fine sediments in remaining accumulations, (3) comparing the invertebrate and fish populations of debris-formed pools and riffle areas, and (4) determining the suitability of riffle areas as spawning sites for pink and chum salmon. Such studies should relate the physical changes observed over the past 30 years to the productivity of the system.

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A Technique for Identifying Treatment Opportunities from Western Oregon and Washington Forest Survey Plots

by Colin D. MacLean

Abstract

Identification of opportunities for silvicultural treatment from inventory data is an important objective of Renewable Resources Evaluation in the Pacific Northwest. This paper describes the field plot design and data analysis procedure used by what used to be known as Forest Survey to determine the treatment opportunity associated with each inventory plot in western Oregon and Washington. Information thus obtained should be of considerable interest to planners, legislators, and public administrators.

KEYWORDS: Survey methods/planning, forest surveys, silvicultural treatments.

CONTENTS

INTRODUCTION

Traditionally, forest inventories were undertaken to determine the available supply of merchantable timber. When old-growth timber was abundant and future timber needs could be met from stored stocks, such inventories met the needs of both managers and planners. As old-growth stocks dwindled, however, interest in immature stands and cutovers--the likely source of future supplies--increased markedly. Thus, there was a need to broaden timber inventory design to include collection of the data needed to assess the condition of cutovers and identify opportunities to improve yields through silvicultural practice.

In order to meet these information needs, new inventory designs were developed. The most common approach (Stage and Alley 1972) (USDA Forest Service, Pacific Northwest Region undated) (Harding 1973) is to prepare a 100-percent stand map and then to sample a representative proportion of the stands, collecting inventory data from a series of sample points. Unsampled stands are usually classified by photo interpretation. The cost of such inventories is high, but the manager of the forest property obtains the needed in-place information about the characteristics and treatment needs of specific forest stands.

Regional and national planners also need to know the condition of cutover lands and the extent of existing opportunities for silvicultural treatment, but they do not need to know the exact location of each treatable stand. Thus, less costly Forest Survey inventories,[1/] based entirely on sample data, are potentially capable of providing the information needed for planning.

The first major Forest Service effort to assess the condition of young-growth forests and cutovers was the "Timber Resources Review" (USDA Forest Service 1958). Much of this assessment was based on special surveys taken to fill in the gaps in Renewable Resources Evaluation data. This experience triggered a substantial effort to design Forest Surveys that were more useful for assessing forest condition and identifying opportunities for silvicultural treatment. One product of this effort was a 10-point, variable-radius plot cluster designed to sample about an acre.[2/] In the Pacific Northwest this 10-point plot was installed on a 3.4-mile (5 470-meter) grid that sampled all conditions of forest land with equal intensity.

[1/]Regularly scheduled Forest Surveys are conducted nationwide, by Renewable Resources Evaluation Research, a project of the USDA Forest Service. The Pacific Northwest Forest and Range Experiment Station conducts the survey in Alaska, California, Hawaii, Oregon, and Washington.

[2/]A. A. Hasel, Plot design of the Forest Survey. Unpublished manuscript on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Several analysts found the new inventory data useful to identify treatment opportunities (Fight and Gedney 1973, Gansner, et al. 1973). In the Pacific Northwest, Fight and Gedney identified treatment opportunities by sorting inventory plots into ownership, age class, stocking class, and broad forest types. Thus, poorly stocked stands were planting opportunities, hardwood stands on conifer site were conversion opportunities, well-stocked stands aged 10 to 30 were precommercial thinning opportunities, etc.

Although the approach produced much useful information, Fight and Gedney were frequently frustrated by the inadequacies of the data, particularly in relation to stocking and age. Even a superficial look at the inventory plots showed that some fell in uneven-aged forests while others sampled clumpy stands where dense thickets were interspersed with open spaces. In addition, the plots often straddled type lines, thus reflecting two or more forest conditions. The average stocking and age levels for such mixed plots were meaningless from a silvicultural point of view. In addition, the small 1-acre (.4-hectare) plots sometimes sampled microconditions too small for feasible treatment. These frustrations led me and my colleagues to: (1) revise the inventory plot design, and (2) develop a new analytical procedure to identify treatment opportunities from individual plot data for the Portland, Oregon Renewable Resources Evaluation Unit.

METHODS

Developing the Techniques

The techniques were developed in conjunction with a regularly scheduled Forest Survey of non-Federal forest lands in western Oregon. The procedures described are currently being used to evaluate treatment opportunities in western Washington and represent the culmination of several years of development. The study was done in five discrete steps: First a procedure to quantify the relative density of each stand component was developed. That stand density measure--expressed as a percent of "normal" density--has already been described (MacLean 1979). Then we selected and defined the silvicultural treatments to be identified. Third, a field design to collect the necessary data was developed. Fourth, an analytical procedure for screening the plot data was developed. Finally, we screened inventory plots and revised procedures to correct for logic errors and to accommodate unforeseen circumstances.

Objectives

Our objective in inventorying treatment opportunities is to identify physical opportunities to increase timber production through silvicultural manipulation of tree stocking. Although our primary interest is in physical opportunities, we also hope to obtain at least some of the inputs needed for subsequent economic analysis. The new procedures are subject to certain constraints:

(1) Information needs must be met from data collected as part of the regular Renewable Resources Evaluation inventories.
(2) Treatment opportunity classification should be based on office evaluation of data rather than subjective field judgment in order to: (a) permit data collection by summer field assistants, (b) obtain consistent classification results, and (c) permit later reevaluation with different treatment criteria.
(3) The analytical procedures used to identify treatment opportunities should be as easy and straightforward as possible and should be applicable over a wide geographic area.
(4) Reasonable results should be expected for stands of mixed ages, mixed species, and variable spacing.

These constraints make it impossible to consider all the subtleties a trained silviculturalist might observe before prescribing for an individual stand. Our intent, however, is not to provide managers with guidance in treating individual stands but to give planners estimates of acreages available for various types of treatment. We hope to develop estimates that are as accurate as is possible within our usual budgetary and manpower limitations.

The Treatments

In western Oregon and Washington, most managers practice some form of even-aged management. Our procedures are predicated on a long-range objective of even-aged management for conifer wood production, even for stands that are presently of mixed species or uneven age. Thus, for treatment identification purposes, all stands are sorted into two species groups--conifer and saleable hardwoods (with or without a conifer component), and conifer stands are further sorted into three stage-of-development categories--mature, intermediate, and regeneration. An additional category--"no manageable stand present"--is used to describe areas where trees are few or lacking or where the stocking of potentially saleable trees is not sufficient to fully utilize the site.

The treatments identified are those which can be expected to increase timber production through manipulation of growing stock. Two other common treatments--fertilization and genetic improvement--are omitted; but potential fertilization opportunities should be identifiable by combining treatment opportunity class with site index and cost information. Genetic improvement, of course, is possible wherever a planting opportunity exists.

Mature Conifer Stands

Mature stands have a density at least 20 percent of normal (MacLean 1979), on at least 60 percent of the area, and exceed the age when mean annual increment of cubic foot volume culminates. Since the exact age of culmination of each stand is not known, we rely on the following broad assumptions for western Oregon and Washington:

Zone	Age of culmination	Source
Conifers growing in Pacific silver fir zone	120 years	(Curtis, Herman, and DeMars 1974)
All west-side conifers except those growing in Pacific silver fir zone	60 years	(Barnes 1962, McArdle et al. 1961)

Mature stands may be candidates for one of the following treatments:

1. Shelterwood removal cut.

This is the final stage of a shelterwood cut, when the regeneration is well established and the remaining overstory can be removed. Overstory density should be less than 50 percent of normal and understory density should be at least 35 percent. Natural stands with a composition that resembles this description will be treated in the same manner.

2. Clearcut.

This is the prescription for stands which fail to qualify for a shelterwood removal cut because of excessive overstory or inadequate understory, unless environmental or land use restrictions make clearcutting undesirable. Stands identical as clearcutting opportunities are also suitable for a shelterwood seed cut.

3. Shelterwood seed cut.

This is the proper description for mature, dense (at least 50 percent of normal density) stands on sites where clearcutting is inappropriate.

4. Shelterwood with harvest delayed until after underplanting.

Some mature stands lack an adequate understory but have too little overstory (less than 50 percent of normal density) to permit a shelterwood seed cut. If such a stand occurs on a site that is unsuitable for clearcutting, then it must be regenerated before the overstory can be removed. Usually site preparation is necessary, and sometimes cull trees must be removed.

Intermediate Conifer Stands

Intermediate conifer stands are below the age of culmination of mean annual increment, have a quadratic mean diameter of at least 20 cm (7.9 in) and have at least 25 percent of normal density on at least 60 percent of the area. Although, normally, such stands are not harvested until maturity, they may be candidates for one of the following treatments:

1. Commercial thinning.

An intermediate harvest in which excess growing stock is removed for sale. Stands that exceed the recommended "maximum" percent of normal density--approximately 75 percent--(Reukema and Bruce 1977) on at least 60 percent of the area are potential candidates for this treatment.

2. Improvement cutting.

The removal of unsaleable material in order to free crop trees from competition. Improvement cutting differs from a commercial thinning in that the material removed is not marketable. Stands are candidates for this treatment if unmarketable tree competition exceeds 20 percent of normal density over at least 60 percent of the area.

3. Sanitation salvage cutting.

The removal of salvable dead trees and trees expected to die within 10 years (high risk trees). When the merchantable volume in salvable dead and high risk conifer trees over 20 cm (7.9 in) in d.b.h. exceeds 70 m^3 per ha (1,000 ft^3 per acre), the stand is a candidate for sanitation salvage cutting.

Conifer Regeneration Stands

These immature stands of growing stock conifers have a quadratic mean diameter of less than 20 cm (7.9 in) and a density that is expected to reach 25 percent of normal on at least 60 percent of the area by the time the quadratic mean diameter of the stand is 20 cm. Such stands may be candidates for one of the following treatments:

1. Precommercial thinning.

Regeneration stands qualify for precommercial thinning, (1) if the average height of the codominant and dominant trees is between 3 and 9 m (9.8 and 29.5 ft) and (2) if, on at least 60 percent of the area, the stand density is expected to exceed 75 percent of normal by the time the quadratic mean diameter of the stand reaches 20 cm (7.9 in). At 20 cm, normal density varies from 970 to 1,340 trees per ha (393 to 542 trees per acre) depending upon species. The standard for smaller trees is slightly higher to account for anticipated mortality.

2. Precommercial thinning of clumps.

Candidates for the precommercial thinning of clumps qualify when at least 30 but less than 60 percent of the area exceeds the density standard.

3. Cleaning or release.

A cleaning is called for when a regeneration stand is partly stocked with brush or hardwoods. If this competition is overtopping the conifers, the treatment is called a release. The usual treatment is with herbicidal sprays. Stands are candidates for cleaning or release when field records indicate substantial competition from brush or hardwoods on at least 60 percent of the area.

4. Prepare site and plant holes.

Sometimes regeneration stands contain nonstocked holes. If these holes make up one-third or more of the area and if competition from trees over 1.5 m (4.9 ft) is absent, the nonstocked patches are suitable for spot planting, after site preparation. This treatment is only suitable for regeneration stands.

5. Improvement cutting.

Candidates for improvement cutting are regeneration stands overtopped by hardwood and cull conifer trees that exceed 20 cm (7.9 in) in d.b.h. when the density of such trees exceeds 20 percent on at least 60 percent of the area. These stands resemble overstory removal opportunities except that the overstory is composed of nonsaleable material.

High-value Hardwood Stands and High-value Hardwood-conifer Mixed Stands

These stands fail to qualify as manageable conifer stands but have at least 25 percent of normal density of red alder (*Alnus rubra* Bong.), black cottonwood (*Populus trichocarpa* Torr. & Gray), and conifers on at least 60 percent of the area. Although these stands are treated as opportunities to convert to conifer production, they are identified separately in order to permit identification of alternative opportunities to manage for hardwood production. The opportunities currently identified are the same as those listed under "Manageable stand absent."

Manageable Stand Absent

Areas that fail to qualify as mature, intermediate, or regeneration stands are assumed not to have a manageable stand. Such stands are candidates for regeneration treatments. Those treatments are:

1. Harvest cutting (clearcutting).

Stands which average at least 70 m^3 per ha (1,000 ft^3 per acre) in conifer and high-value hardwood trees over 20 cm in d.b.h. are candidates for clearcutting.

2. Stand conversion.

Candidates for stand conversion are areas where a manageable stand is absent and the volume per acre is less than 70 m^3 per ha but where the density of trees over 20 cm in d.b.h. is at least 20 percent on 60 percent of the area. This treatment calls for removing the existing trees and planting the area with desirable growing stock.

3. Site preparation and planting.

Candidates for removal of competing vegetation and for planting are areas where a manageable stand is absent and the density of trees over 20 cm in d.b.h. is inadequate for stand conversion.

Plot Design

The data for treatment opportunity analysis are collected during the course of regularly scheduled Renewable Resources Evaluation timber inventories. In the Pacific Northwest, field plots are located on a 5 470-m (3.4-mi) grid. Each grid point is located on an aerial photo, and forest stands are delineated in the immediate vicinity. The minimum area for this delineation is 3 ha (7.4 acres). The grid point is then located in the field, and a 5-point cluster is established within the type-island associated with the grid point. If possible, the points are layed out in the pattern illustrated in figure 1. Where necessary, points are moved in a predetermined pattern to insure that the area sampled falls entirely within the type-island, thus avoiding plots that straddle condition-class boundaries. If the average diameter of the conifer trees on the plot is less than 12 cm (4.7 in), an additional five points may be established midway between the initial five plots.

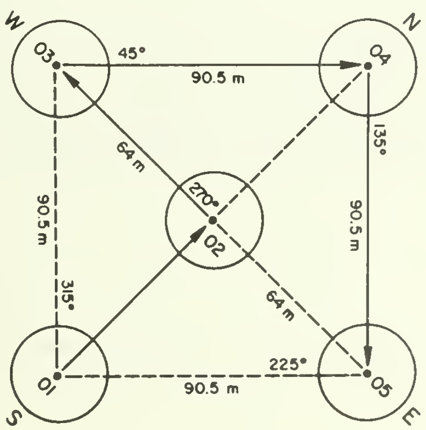

Figure 1.--Inventory plot layout.

At each sample point, three plots are established as follows:

Trees tallied	Plot size
(1) All trees up to 17.5 cm (6.9 in) in diameter	0.004-ha (.01-acre) fixed radius plot.
(2) Trees between 17.5 cm and 89.9 cm (35.4 in) in diameter	Metric basal area factor 7 (English BAF 30.5) variable radius plot
(3) Trees over 89.9 cm in diameter	0.09-ha (0.22-acre) fixed-radius plot

Species, d.b.h., crown class, crown ratio, total height, age, defect, and damage class is recorded for each tally tree. In addition, trees in the main canopy are separated from understory trees. Sometimes a few large trees--the remnants of past logging or fire--are scattered through regeneration stands. Such trees are separately identified as residual overstory.

Information is collected on competing vegetation, including a record of the degree to which growing stock trees are shaded by competing brush or hardwoods. The site index, topographic class, and stand history of each sampled stand is also recorded as well as information on erosion, land-use conflicts, and environmental factors affecting treatment.[3]

Tree Classification

The first step in classification of the field plot data is to assign tree class designations to each tally tree. The major tree categories--main stand (overstory), future stand (understory), residual overstory, conifer and hardwood--are assigned in the field. Additionally, objective criteria are used to classify each tree as follows:

1. Mature tree.

A conifer, black cottonwood, or red alder that has passed the age when mean annual increment is assumed to culminate and is expected to live longer than 10 years.

2. High risk tree.

A merchantable conifer, red alder, or cottonwood likely to die within 10 years because of disease, injury, or poor vigor, as indicated by damage codes recorded on the plot card.

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[3]Field procedures are described in detail in a treatment opportunity field manual on file at the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

3. Immature growing stock tree.

A presently or potentially merchantable conifer, red alder, or cottonwood tree that is less than the presumed age for culmination of mean annual increment.

4. Low-value hardwood.

A hardwood other than red alder or cottonwood. Such trees are not now considered suitable for potential timber crop trees because of poor prospects for a present or future market.

5. Cull tree.

A tree that is unmerchantable because of rot or poor form.

6. Salvable dead tree.

A dead tree that is still at least 25-percent sound and merchantable.

Plot Classification

Initial screening.--Before inventory plots are classified for treatment opportunity, certain plots may be identified as representing areas unsuitable for management because treatment is not feasible or is unlikely to succeed. Such plots usually occur on hot, dry sites where productivity is low and regeneration hazard is high. Identification of these areas is based on guidelines obtained from forest managers and ecologists familiar with the region. Hardwood stands growing on hardwood sites--usually river bottoms--are also identified as unsuitable for treatment because of the poor market for most hardwood species. Poorly stocked recent clearcuts--cut within 5 years--and stands partially cut within 3 years are placed in a special category. Since the regeneration of clearcuts is now a legal obligation, we assume they are awaiting scheduled treatment. The success of regeneration after recent partial cutting will be evaluated at the time of the next inventory.

Identifying the management category.--After initial screening, each plot is placed in one of the seven management categories. First, the plot is examined to see whether at least three of the five points qualify as mature conifer. If not, the plot is reexamined to see if three points qualify as intermediate conifer. This process is repeated until a management category is found that fits the plot tally on at least three points. The order of categories tested is (1) mature conifer, (2) intermediate conifer, (3) conifer regeneration, (4) high-value hardwood, (5) high-value hardwood-conifer mixed. Stands which do not fit any of these categories are classed as "manageable stand absent." The process is illustrated in figure 2.

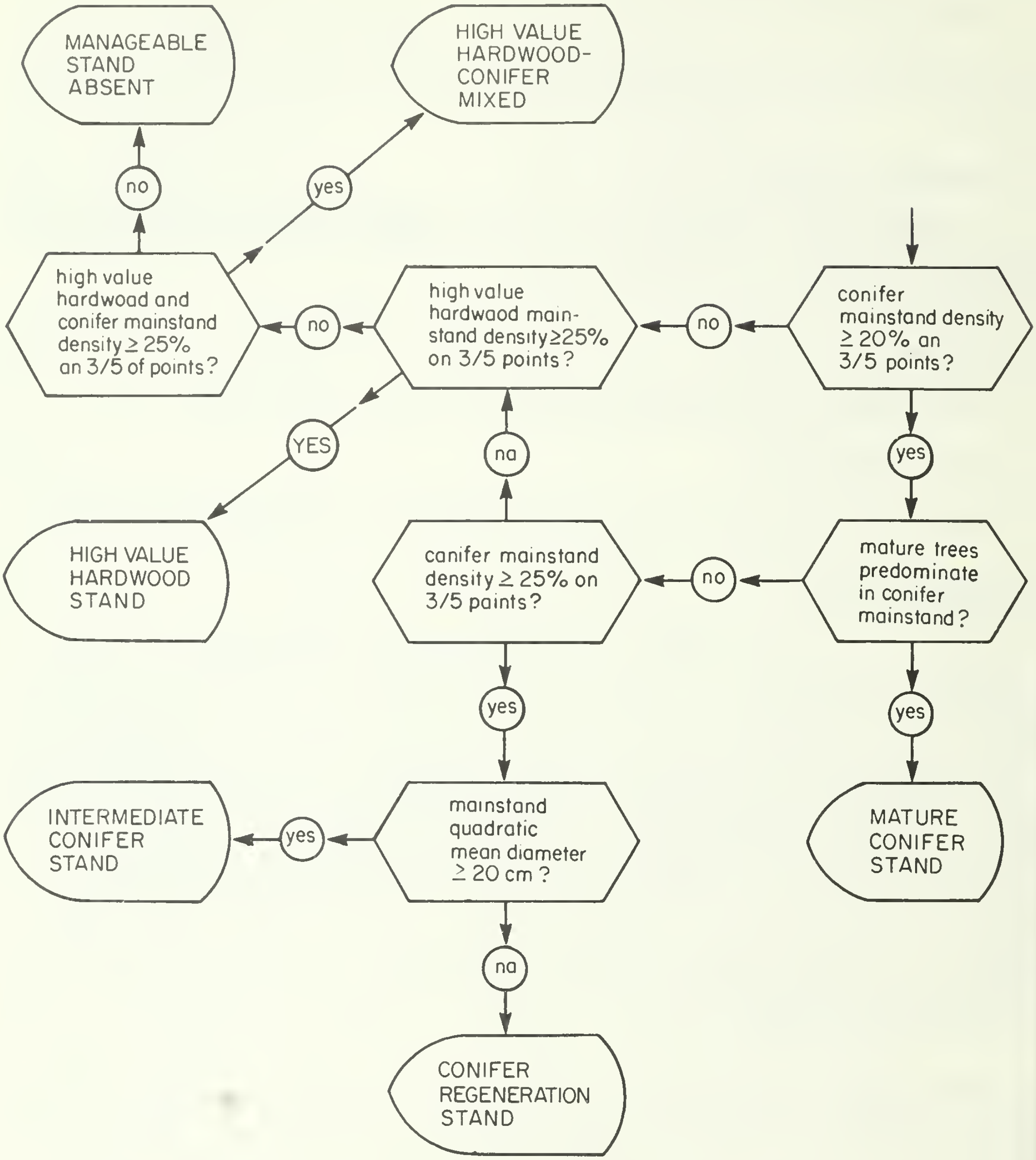

Figure 2.--Treatment opportunity logic: Identifying the management category.

The primary tool for this plot classification is a computer printout showing the stand density at each sample point by (1) softwoods and hardwoods, (2) stand position (mainstand, future stand, and residual overstory), and (3) tree class. An example of this printout is shown in table 1. Based on these density data, the management category is first determined; and then within that category, the actual treatment--occasionally treatments--are identified.

Treatment opportunities in mature stands.--The age at which a manager harvests timber varies widely with organization objectives, multiple-use policies, and a variety of economic considerations. Stands classed as mature in our analysis may add substantial growth if held for later harvest. On the other hand, somewhat younger harvest ages will not greatly reduce the long-term total yield. In any event, stands classed as mature in this analysis have passed the point where large increases in productivity are possible through manipulation of existing growing stock.

Mature stands are identified as opportunities to clearcut and regenerate except in stands (1) qualifying for a shelterwood removal cut, or (2) in areas where clearcutting is unacceptable because of regeneration hazard or other environmental restraints. Areas not suitable for clearcutting because of regeneration hazard are identified by local criteria obtained from managers and ecologists familiar with the area. Such areas are candidates for a shelterwood seed cut, a shelterwood removal cut, or for underplanting, depending on the characteristics of the stand. The logic used to identify these opportunities for treatment is illustrated in figure 3.

Treatment opportunities in intermediate stands.--Intermediate stands, although not ready for final harvest, have passed the age where large yield increases are possible through silvicultural manipulation of growing stock. The denser stands, however, may be candidates for commercial thinning to reduce capital investment and to increase the size of the trees to be removed in the final harvest. In addition, the growth of some stands may be increased by removing culls, hardwoods, and high-risk trees. The logic used to identify these treatments is illustrated in figure 4.

Treatment opportunities in regeneration stands.--Regeneration stands are at the stage of development where silvicultural treatment can often have considerable impact on future yield (Reukema and Bruce 1977). Timely precommercial thinning can redistribute growth to those trees most likely to survive until harvest and increase height growth as well, and the planting of nonstocked openings can return such areas to timber production. Additionally, the control of hardwood and brush competition can substantially increase future yields.

The logic used to identify opportunities for silvicultural treatment in regeneration stands is illustrated in figure 5.

Table 1--Example of display of stand density by point and by stand component

S O U T H W E S T   W A S H I N G T O N

STATE	53	PLOT SEQUENCE	68	NUMBER OF POINTS	5	QUADRATIC MEAN DIAMETER, MAINSTAND	(CON= 28.22 HWD= 0.00)	
COUNTY	15	PLOT NUMBER	12	STOCKING POINTS	0	QUADRATIC MEAN DIAMETER, FUTURE STAND	(CON= 5.24 HWD= 7.61)	
						PROPORTION OF STOCKABLE AREA		1.00
						SALVABLE DEAD STOCKING		0.00

PERCENT OF NORMAL DENSITY FOR PLOT 12

	1/		SOUND CULL	ROTTEN CULL	-GROWING STOCK- LO-VALUE HARDWOOD	----SOFTWOOD/RED ALDER/COTTONWOOD----- HIGH RISK	IMMATURE	MATURE	TOTAL	TOTAL POINT STOCKING
POINT 1 (CC=99)	M/S	SFTWDS	0.0	0.0	0.0	0.0	23.1	0.0	23.1	
	M/S	HRDWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	F/S	SFTWDS	0.0	0.0	0.0	0.0	105.4	0.0	105.4	
	F/S	HRDWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	R/O	SFTWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	R/O	HRDWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	TOTAL		0.0	0.0	0.0	0.0	128.5	0.0	128.5	128.5
POINT 2 (CC=99)	M/S	SFTWDS	0.0	0.0	0.0	0.0	44.3	0.0	44.3	
	M/S	HRDWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	F/S	SFTWDS	0.0	0.0	0.0	0.0	35.0	0.0	35.0	
	F/S	HRDWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	R/O	SFTWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	R/O	HRDWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	TOTAL		0.0	0.0	0.0	0.0	79.3	0.0	79.3	79.3
POINT 3 (CC=99)	M/S	SFTWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	M/S	HRDWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	F/S	SFTWDS	0.0	0.0	0.0	128.0	153.2	0.0	281.2	
	F/S	HRDWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	R/O	SFTWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	R/O	HRDWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	TOTAL		0.0	0.0	0.0	128.0	153.2	0.0	281.2	281.2
POINT 4 (CC=19)	M/S	SFTWDS	0.0	0.0	0.0	0.0	12.6	0.0	12.6	
	M/S	HRDWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	F/S	SFTWDS	0.0	0.0	0.0	0.0	108.8	0.0	108.8	
	F/S	HRDWDS	0.0	0.0	0.0	0.0	44.5	0.0	44.5	
	R/O	SFTWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	R/O	HRDWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	TOTAL		0.0	0.0	0.0	0.0	166.0	0.0	166.0	166.0
POINT 5 (CC=99)	M/S	SFTWDS	0.0	0.0	0.0	0.0	12.6	0.0	12.6	
	M/S	HRDWDS	47.8	0.0	0.0	0.0	0.0	0.0	0.0	
	F/S	SFTWDS	0.0	0.0	0.0	0.0	237.5	0.0	237.5	
	F/S	HRDWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	R/O	SFTWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	R/O	HRDWDS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	TOTAL		47.8	0.0	0.0	0.0	250.1	0.0	250.1	297.8

1/ MS = Mainstand,
FS = Future stand,
RO = Residual overstory.

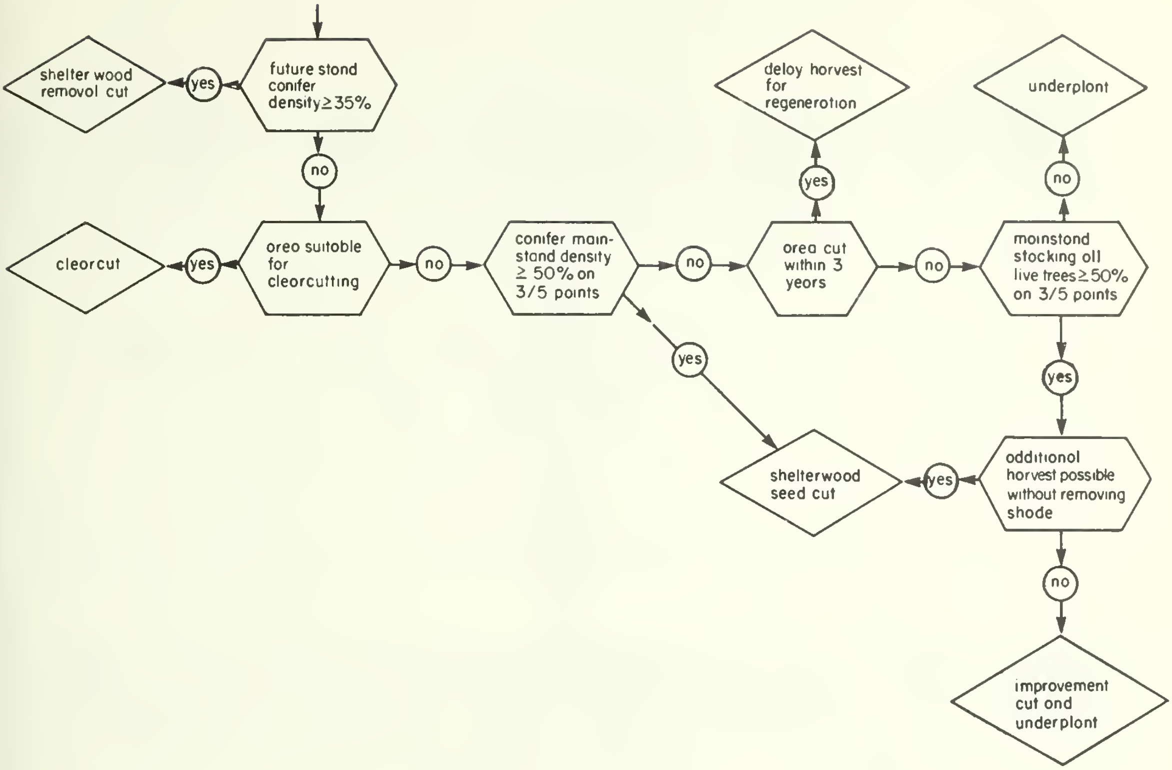

Figure 3.--Treatment opportunity logic for mature stands.

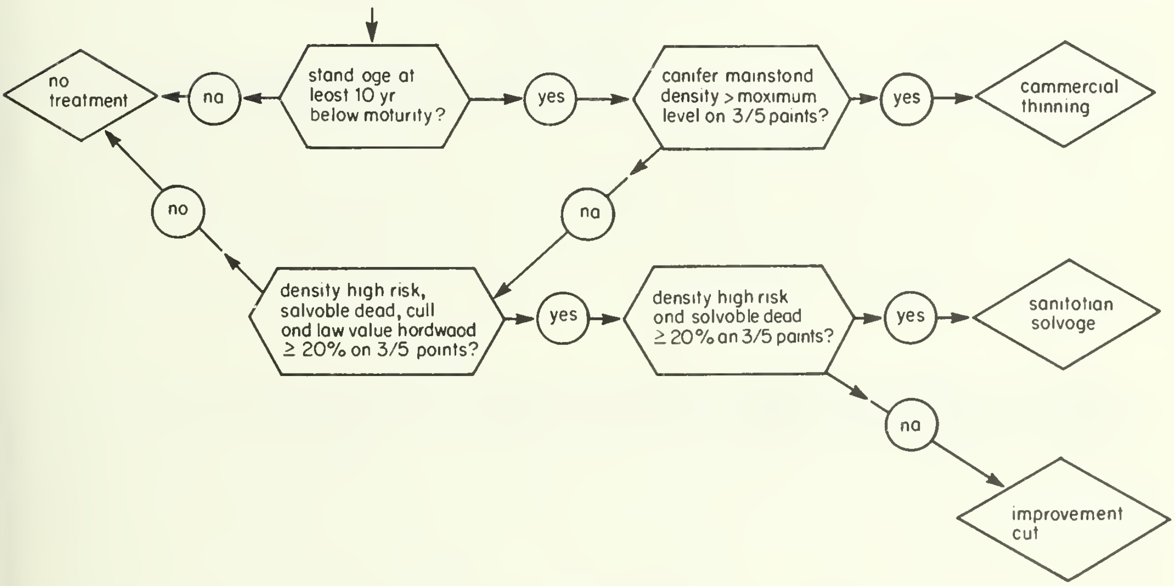

Figure 4.--Treatment opportunity logic for intermediate stands.

Figure 5.--Treatment opportunity logic for regeneration stands.

Treatment opportunities in hardwood stands and areas where no manageable stand exists.--The greatest opportunity to increase timber production through silvicultural treatment is to regenerate areas now growing weeds, brush, and low-value hardwoods. Further increases may be realized by replacing stands of red alder and poorly stocked conifer with new conifer regeneration stands. In our analysis, all such stands are regarded as opportunities for replacement. The logic for identifying such opportunities is illustrated in figure 6. Red alder stands are, however, identified separately. If the demand for that species improves, we may want to consider growing alder as an alternative to replacement.

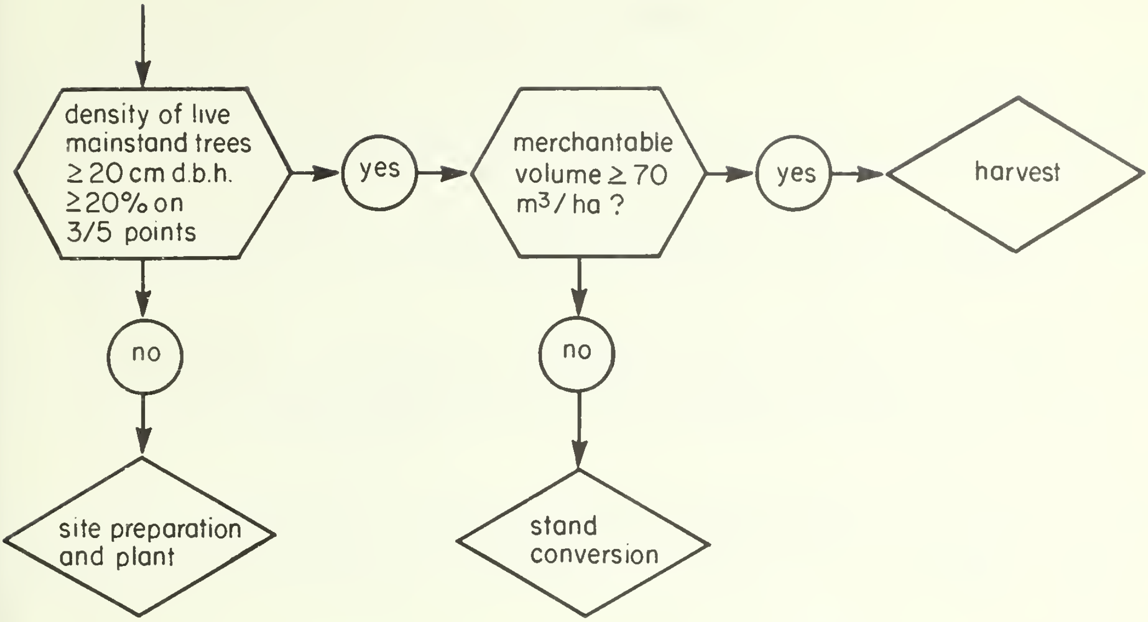

Figure 6.--Treatment opportunity logic for areas where no manageable stand exists.

FURTHER REFINEMENTS

We have now analyzed treatment opportunity data from western Oregon and will soon begin an analysis of western Washington data. We are making the same analysis in eastern Oregon but with slightly altered criteria to reflect the different conditions that exist on the east side of the Cascade Range. In our initial work, we have hand-screened the data to make sure that each plot has been assigned a reasonable treatment. While this process has uncovered a few defects, the results have been generally good. Our experience in analyzing western Washington data will undoubtedly permit further refinement.

While the procedures now work well, some subjective verification of results will probably always be necessary, particularly in heavily disturbed stands. A system complex enough to anticipate all conditions that may be encountered in the woods is probably neither possible nor desirable.

Thus far, treatment opportunity classification has proved a very useful tool for assessing forest condition. Preliminary analyses have also convinced us that it will provide an excellent means of stratifying our inventory in order to project future timber supply under various assumptions.

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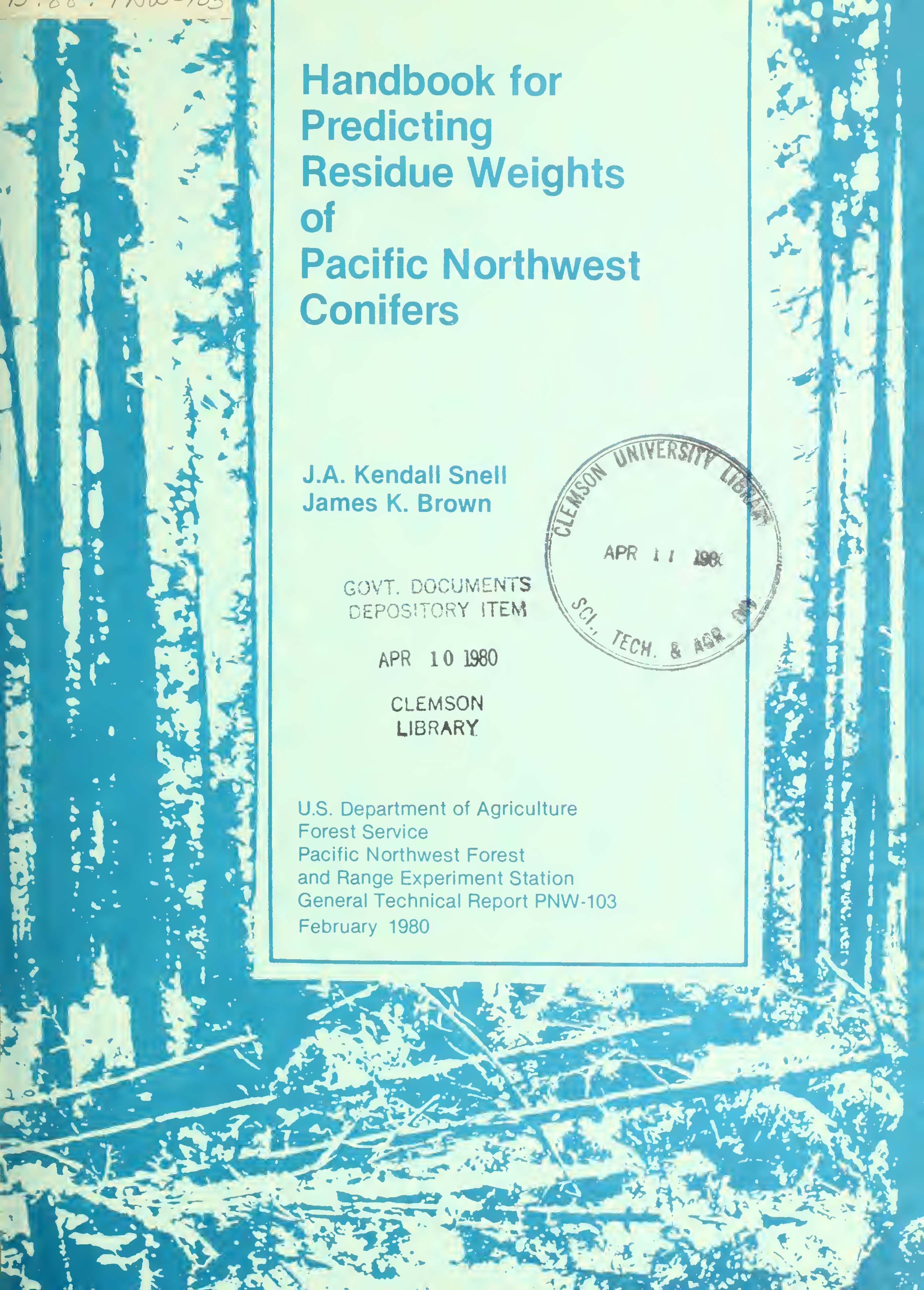

Handbook for Predicting Residue Weights of Pacific Northwest Conifers

J.A. Kendall Snell
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ABSTRACT

Procedures are given for estimating weights of potential residue from Douglas-fir and western hemlock created by forest management activities west of the summit of the Cascade Range. Preliminary estimates are given for six other species. The weight tables are in pounds per tree and pounds per square foot of basal area for a 6- or 8-inch unmerchantable tip. The estimates are also separated into material of: $<$3-inch and $\geq$3-inch diameter and total weight. The tabular weights include foliage, live and dead branchwood, and unmerchantable tip.

KEYWORDS: Biomass, residue weights, conifers, weight tables.

PREFACE

This handbook provides instructions and information for predicting crown weights of conifers west of the summit of the Cascade Range. It is an extension of the "Handbook for Predicting Slash Weight of Western Conifers," by Brown et al. (1977). That handbook was intended for use in predicting crown weight of conifers in western Montana and northern Idaho, but its use has grown to include all the Northwest United States east of the summit of the Cascade Range. Other than geographical use of these two handbooks, the principal difference is the addition, in this handbook, of the weight table for material $\geq$3-inch diameter and the extension of diameter at breast height (d.b.h.) from 40 to 80 inches. The extension of the tables beyond 40-inch d.b.h. is based on data collected for Douglas-fir and western hemlock. The weights for other species beyond 40-inch d.b.h. were developed from weight ratios with Douglas-fir at 40-inch d.b.h. (see tables 12 and 13 in the appendix).

Special thanks are due James Atkins for expediting compilation of the tables through efficient programing.

CONTENTS

APPROXIMATE CONVERSIONS TO METRIC UNITS

When you know	multiple by	to find
inches	2.540	centimeters
feet	0.305	meters
pounds	0.454	kilograms
pounds/square foot	4.883	kilograms/square meter
tons/acre	2.242	metric tonnes/hectare
cubic feet/acre	0.070	cubic meters/hectare

Scientific and Common Names of Tree Species

Scientific name	Common name
Abies amabilis Dougl. ex Forbes	Pacific silver fir
Abies concolor (Gord. and Glend.) Lindl. ex Hildebr.	white fir
Abies grandis (Dougl. ex D. Don) Lindl.	grand fir
Abies lasiocarpa (Hook.) Nutt.	subalpine fir
Abies magnifica var. shastensis Lemm.	shasta red fir
Abies procera Rehd.	noble fir
Chamaecyparis nootkatensis (D. Don) Spach	Alaska-cedar
Larix occidentalis Nutt.	western larch
Libocedrus decurrens Torr.	incense-cedar
Picea engelmannii Parry ex Engelm.	Engelmann spruce
Picea glauca (Moench) Voss	white spruce
Picea sitchensis (Bong.) Carr.	sitka spruce
Pinus albicaulis Engelm.	whitebark pine
Pinus attenuata Lemm.	knobcone pine
Pinus contorta Dougl. ex Loud.	lodgepole pine
Pinus jeffreyi Grev. and Balf.	Jeffrey pine
Pinus lambertiana Dougl.	sugar pine
Pinus monticola Dougl. ex D. Don	western white pine
Pinus ponderosa Dougl. ex Laws.	ponderosa pine
Populus tremuloides Michx.	quaking aspen
Populus trichocarpa Torr. and Gray	black cottonwood
Pseudotsuga menziesii (Mirb.) Franco var menziesii	coast Douglas-fir
Sequoia sempervirens (D. Don) Endl.	redwood
Thuja plicata Donn ex D. Don	western redcedar
Tsuga heterophylla (Raf.) Sarg.	western hemlock

INTRODUCTION

This handbook contains procedures for predicting weights of logging and thinning residue, such as needles, branches, unmerchantable tips, and broken and defective boles. In the past, this residue has been difficult to quantitatively describe before it was created, and associated problems were difficult to determine and evaluate. Prediction of such material does not guarantee easy solutions to management problems but rather provides a sound foundation for making decisions and formulating plans.

Weight estimates of residue can be useful in the following situations: (1) communicating the magnitude of residue problems, (2) writing disposal contracts, (3) describing potential for utilization, (4) selecting among alternative treatments, and (5) appraising potential fire behavior of fuels.

Residue is produced from three parts of a tree: (1) crowns (foliage and branches), (2) unmerchantable tips, and (3) defective and broken boles (fig. 1). Tables 1-10 include the crown and unmerchantable tip weights, but they do not include the defective and broken boles; this weight must be estimated by a separate procedure (see page 4).

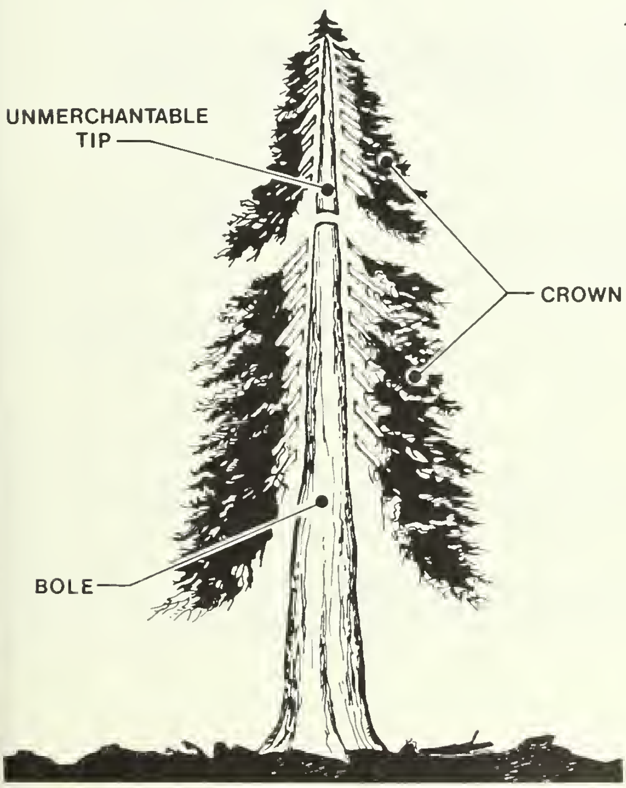

Figure 1.--Different relationships are required to predict weight of residue produced from crowns (foliage and dead and live branchwood), unmerchantable bole tips, and boles (defective and broken).

The weights in tables 1-10 were derived from studies by Brown (1978), Faurot (1977), and the Forest Residue Program, Pacific Northwest Forest and Range Experiment Station.[1] For explanations, see the appendix.

Predicting weights of created residue for many different species and tree sizes is a job for computers. Computer programs for calculating such weights have been developed for some Regions of the USDA Forest Service. Since these programs are not readily available to everyone, this handbook was assembled to be used as a substitute to calculate potential residue weights when access to computer prediction programs is not available or is inconvenient.

The total amount of residue after logging or thinning is the sum of the residue present before and after logging or thinning. The residues present before logging or thinning can be of major importance for evaluating fire potential; sometimes this material weighs as much as or more than the created residue.

PROCEDURES USED TO MAKE RESIDUE PREDICTIONS

Residue weights can be predicted for cut or trampled trees from estimates of (1) trees per acre by species and d.b.h. or (2) basal area per acre by species and d.b.h. Tables 1-10 include weights of crowns (foliage, live and dead branchwood) and unmerchantable tips to either a 6-inch or 8-inch merchantable top diameter.

The tables are designed so the user can estimate weight of: (1) branches and unmerchantable tips that are <3 inches in diameter (includes foliage), (2) branches and unmerchantable tips that are ≥ 3 inches in diameter, and (3) total weight (sum of 1 and 2).

The separation of the material at 3 inches in diameter coincides with the required inputs for a mathematical fire appraisal program, called HAZARD.[2]

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[1]Predicting crown weight of Pacific Northwest Douglas-fir and western hemlock. Unpublished data on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

[2]Developed by Frank A. Albini, Northern Forest Fire Laboratory, Missoula, Montana, and maintained by the USDA Forest Service, Northern Region, Aviation and Fire Management, Missoula, Montana.

Residue weights can be predicted and summarized along with prelogging or prethinning down woody fuels in four basic steps:

1. Gather and summarize tree inventory data.
2. Calculate weight from cutting and trampling.
3. Calculate weight for tree defect and breakage.
4. Inventory down and dead woody material.

Step 1--For the area of interest, summarize inventory data of trees to be cut, by number of trees per acre by species and d.b.h., or by basal area per acre by species and d.b.h., whichever form is more convenient.

Summarize the tree inventory data by 1-inch d.b.h. classes, or by d.b.h. groups; use the average d.b.h. of each group for determining weights (for example, for 5-10 inches, use midpoint--8). Residue weight from both cutting and trampling can be estimated for the area by including in the summary only the trees that are expected to be either cut or trampled (trampling is the pushing over of small trees by logging equipment). Trampling seldom occurs in thinning operations and may be negligible in many harvesting areas. Where substantial trampling is expected, however, its contribution to residue can be estimated by procedures described later.

Step 2--Select the desired weight table and multiply either the number of trees or the basal area per acre times the appropriate table values for crown weight for each species d.b.h. group. Sum all weights to obtain the total crown weight per acre.

For harvest cutting, choose the appropriate weight table--either for material $<$3-inch diameter, $\geq$3-inch diameter, or total--for either a 6- or 8-inch merchantable top diameter. If the top diameter specification is other than 6 or 8 inches, use the one that most closely approximates the specified top diameter.

Since trees being thinned or trampled are generally small, their entire bole is left onsite. For these trees, the values above the dashed line in tables 2, 3, 4, 5, 7, 8, 9, and 10 should be used, since these weights include the entire bole and crown. It must be remembered, though, that some tables contain only that portion of the weight that is $\geq$3 inches in diameter. For trees below the dashed line, only the unmerchantable tip and crown weight are included; that portion of the bole below the unmerchantable tip is excluded.

Step 3--Estimate residue weight for tree defect and breakage.

Defect and breakage of trees are far more difficult to predict than weights of crowns and unmerchantable tips. Nonetheless, an estimate is possible from experience and knowledge of local harvesting operations. This estimate cannot be obtained from the enclosed tables, but a general procedure describing how to estimate these weights will be given. Residue from defect and breakage is considered larger than 3 inches in diameter and should be added only to weights obtained from the ≥3 inches and total weight tables.

Defect--such as rot, crook, sweep, fire scars, butt swell, etc.--varies by species and tree size. Most timber sellers have some notion of defect percentage (fraction of merchantable volume that is defective) applicable to their area. Not all defect remains on the cutting site, however; some of it is hauled to the mill. Thus, defect percentages must represent the material actually remaining onsite.

Breakage can best be estimated from local experience with past harvesting operations. In the Pacific Northwest, breakage in old-growth stands is commonly estimated at 15 percent of the cruised merchantable volume. For second-growth stands, 5 percent is not uncommon (opinions of several experienced foresters in USDA Forest Service Pacific Northwest Region).

To make weight estimates of either breakage or defect, an estimate of merchantable volume per acre is needed. This volume may be obtained from a timber cruise or formal stand examination. Wood densities (weight per unit volume) are then used to change volume to weight. Densities for common western tree species are summarized in table 11. For a mixture of species, densities can be averaged. A wood density representing a commonly encountered mixture of western conifer species is 25 pounds per cubic foot.

Step 4--Inventory the weight of dead and down woody material and add it to appropriate weight predicted from weight tables.

Refer to Brown's (1974) "Handbook for Inventory Downed Woody Material."

Sample Prediction

To illustrate the steps used to estimate weight of potential residue from the tables, consider a partial harvest of Douglas-fir and western hemlock. The specified merchantable top diameter for this example is 8 inches. The trees to be cut are summarized by species and d.b.h. on the RESIDUE WEIGHT SUMMARY form (fig. 2). The four steps are the guide for this example. As an aid to the user, a blank RESIDUE WEIGHT SUMMARY form is included at the back of this publication.

RESIDUE WEIGHT SUMMARY

STAND 16 LOCATION DEEP CR. UNIT 1 DATE 5-15-79

<3 ______ ≥3 ______ TOTAL X TOP DIA. 8.0

Number of trees/acre from inventory by species							Crown weight/acre (pounds) by species					
DBH	DF	WH					DF	WH				
1		60						168				
2		30						369				
3		—						—				
		90						537				
10												
12		12						5208				
14		6						2736				
16												
18		4						2176				
20		5						3025				
22	2	2					1274	1352				
24	3						2133					
26	2						1692					
	—	—					—	—				
	7	29					5,099 +	14,497 =	19,596			

SUMMARY OF RESIDUE WEIGHT

(1) CUTTING		(2) TRAMPLING		(3) DEF. & BREAKAGE	
Pounds/acre	Tons/acre	Pounds/acre	Tons/acre	Pounds/acre	Tons/acre
19596	9.8	537	.27	8527	4.26

PREDICTED WEIGHT, (1) + (2) + (3) Tons/acre = 14.33

(4) EXISTING DOWNED RESIDUE, Tons/acre = 18.00

TOTAL RESIDUE (1) + (2) + (3) + (4), Tons/acre = 32.33

Page 1 of 1

Figure 2.--A completed residue weight summary form.

(1) CUTTING:

Step 1--Estimate number of trees to be cut per acre, by species and d.b.h., and record on left side of RESIDUE WEIGHT SUMMARY form (fig. 2). In this example, there are 29 western hemlock (12- to 22-inch d.b.h.) and 7 Douglas-fir (22- to 26-inch d.b.h.) trees per acre to be cut. It is also estimated that 90 western hemlock trees (1- and 2-inch d.b.h.) per acre will be trampled.

Step 2--Select the appropriate weight table to be used. For this example table 5 will be used because total residue weight is needed for a merchantable top specification of 8 inches.

Example: There will be 12 western hemlock trees with a d.b.h. of 12 inches cut per acre. The residue weight estimate for a 12-inch d.b.h. western hemlock is 434 pounds (table 5); thus,

$$12 \times 434 = 5{,}208 \text{ lb/acre.}$$

The remaining trees per acre are similarly estimated; summed, the total is 9.80 tons/acre.

(2) TRAMPLING: It was estimated that sixty 1-inch d.b.h. and thirty 2-inch d.b.h. western hemlock will be trampled. Their predicted weight is:

$$[(60 \times 2.8)+(30 \times 12.3)] \div 2{,}000 = 0.27 \text{ ton/acre.}$$

(3) DEFECT AND BREAKAGE:

Step 3--A timber cruise indicated the volume to be harvested was $2,992\ ft^3$ per acre, 80-percent western hemlock and 20-percent Douglas-fir. Of the merchantable volume per acre, about 10 percent will be left in the woods; 5 percent for defect and 5 percent for breakage. To change volume to weight, multiply by a weighted average density. See table 11 for densities of species. For this example, the weighted density would be:

$$[80 \text{ percent} \times 28.1 + 20 \text{ percent} \times 30.0] \div 100 = 28.5.$$

The volume left onsite is then changed to weight by the following formula:

$$W = V \times f \times s/2{,}000;$$

where:
W = weight of logging residue from defect and breakage, tons/acre;
V = merchantable volume of trees to be cut, ft^3/acre;
f = fraction of merchantable volume expected to be left on the ground as defect and breakage;
s = density of wood, lb/ft^3; and
2,000 changes pounds to tonnes.

For this example:
$V = 2{,}992\ ft^3$;
f = 0.05 defect plus 0.05 breakage which equals 0.10;
$s = 28.5\ lb/ft^3$ (weighted average previously calculated); and
$W = (2{,}992 \times 0.10 \times 28.5) \div 2{,}000 = 4.26$ ton/acre.

Residue predicted from cutting, trampling, and defect and breakage is: 9.80 + 0.27 + 4.26 = 14.33 ton/acre.

(4) DEAD AND DOWN WOODY MATERIAL:

Step 4--An inventory of dead and down woody material in the area yielded 18.00 tons/acre.

Total residue predicted, then, is: 14.33 + 18.00 = 32.33 ton/acre.

Other Species and Crown Classes

Procedures outlined in the previous section can be used with unknown but probably acceptable accuracy on species that have branching habits similar to the species listed in the tables. The following combinations of species are probably similar enough to yield reasonably accurate residue predictions when considered alike:

Listed in tables	Like species not listed in tables
Lodgepole pine	Knobcone and white bark pine
Grand fir	Shasta red fir and white fir
Western redcedar	Incense-cedar
Western white pine	Sugar pine
Ponderosa pine	Jeffrey pine

The tables in this handbook were developed from data for trees having dominant and codominant crown classes.[3] Brown (1978) found that crown weight of intermediate trees of shade-tolerant species is not significantly different from that of dominant and codominant trees. For shade-intolerant species, however, crown weight of intermediate trees is significantly less than that of dominant and codominant trees. Thus, in stands of tolerant species where a large proportion of the trees have intermediate crowns, an adjustment of the crown weight based on dominant and codominant trees may be desirable.

We recommend adjusting crown weights only for ponderosa pine, lodgepole pine, and western larch. When these species dominate the composition and have a high proportion of intermediate trees, adjusted crown weights can be calculated as follows:

D.b.h.	Equation
Less than 7.5 inches	$D' = D(1 - 0.5f_I)$
7.5 inches and greater	$D' = D(1 - 0.4f_I)$

where:

D' = crown weight per acre adjusted for intermediate trees,
D = crown weight per acre based on dominant and codominant trees, and
f_I = fraction of trees per acre having intermediate and suppressed crowns.

[3] Weights for Douglas-fir were developed from trees of all crown classes.

Residue Weight (lb) per

TREE

TABLE 1--WEIGHT OF RESIDUE PER TREE BY D.B.H., OF FOLIAGE AND THAT PORTION OF THE BRANCHWOOD (LIVE AND DEAD), AND UNMERCHANTABLE TIP THAT IS ≤3 INCHES IN DIAMETER

≤3 INCHES

	SPECIES[1]							
D.B.H.	DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[2]							
1	2.9	3.1	2.4	2.1	3.7	3.8	2.8	5.0
2	11.6	11.9	9.8	11.2	12.1	12.7	11.3	17.2
3	18.1	21.6	16.7	20.3	19.0	21.2	18.3	29.5
4	29	37	26	33	29	33	29	47
5	40	54	35	46	38	46	41	66
6	57	78	47	64	51	62	58	90
7	74	104	58	77	60	79	71	113
8	90	131	65	95	70	96	87	139
9	109	161	75	116	82	115	107	168
10	129	193	86	137	94	135	128	198
11	148	222	97	154	105	152	150	224
12	169	254	108	173	116	171	173	252
13	191	288	121	193	128	191	199	281
14	216	324	135	215	141	212	227	312
15	240	362	150	238	155	235	256	345
16	268	403	165	263	169	258	288	378
17	296	445	181	290	183	282	321	413
18	327	489	198	318	199	308	356	450
19	359	535	215	348	215	334	394	488
20	393	583	233	379	231	361	433	527
21	428	631	252	412	248	390	473	568
22	465	681	271	446	265	419	516	611
23	503	732	291	482	283	449	561	654
24	542	784	311	520	301	481	607	699
25	586	839	336		342	536	659	767
26	628	892	358		360	568	709	814
27	672	947	380		378	601	760	863
28	716	1000	403		398	634	814	913
29	763	1060	426		417	669	870	965
30	810	1110	450		437	705	927	1020
31	859	1170	475		458	741	986	1070
32	908	1220	500		479	779	1040	1130
33	959	1280	525		500	818	1090	1190
34	1010	1330	552		522	857	1140	1250
35	1060	1410	578		545	898	1190	1310
36	1120	1500	606		567	939	1240	1370
37	1170	1580	634		591	982	1290	1430
38	1230	1670	663		614	1030	1340	1500
39	1290	1760	692		638	1070	1390	1570
40	1350	1860	721		662	1110	1450	1630

TABLE 1--CONTINUED

D.B.H.	DF	PP	WL	LP	WP	WC	WH	GF
	SPECIES[1]							
INCHES	POUNDS[2]							
41	1400	1950	761		700	1160	1500	1720
42	1460	2050	797		732	1220	1550	1810
43	1520	2140	834		765	1280	1600	1890
44	1590	2240	872		799	1340	1650	1980
45	1650	2340	911		833	1400	1730	2080
46	1710	2440	950		868	1460	1800	2170
47	1770	2550	990		904	1520	1880	2270
48	1840	2660	1030		941	1580	1950	2370
49	1900	2770	1070		978	1650	2030	2470
50	1970	2880	1120		1020	1720	2110	2570
51	2040	2990	1160		1060	1790	2190	2680
52	2100	3110	1200		1100	1860	2280	2790
53	2170	3230	1250		1140	1930	2360	2900
54	2240	3350	1300		1180	2000	2450	3020
55	2300	3470	1340		1220	2080	2540	3140
56	2370	3600	1390		1260	2150	2630	3260
57	2440	3730	1440		1300	2230	2720	3380
58	2510	3860	1490		1350	2310	2810	3510
59	2580	3990	1540		1390	2390	2910	3640
60	2650	4130	1590		1440	2470	3010	3770
61	2720					2550	3100	3900
62	2790					2640	3200	4040
63	2860					2730	3300	4180
64	2930					2810	3410	4320
65	3000					2900	3510	4470
66	3070					2990	3620	4620
67	3150					3090	3720	4770
68	3220					3180	3830	4930
69	3290					3280	3940	5080
70	3360					3370	4060	5240
71	3430					3470		
72	3500					3570		
73	3570					3680		
74	3650					3780		
75	3720					3880		
76	3790					3990		
77	3860					4100		
78	3930					4210		
79	4000					4320		
80	4070					4430		

[1]DF = DOUGLAS-FIR; PP = PONDEROSA PINE; WL = WESTERN LARCH; LP = LODGEPOLE PINE; WP = WESTERN WHITE PINE; WC = WESTERN REDCEDAR; WH = WESTERN HEMLOCK; GF = GRAND FIR.

[2]OVENDRY WEIGHT.

TABLE 2--WEIGHT OF RESIDUE PER TREE BY D.B.H., OF THAT PORTION OF THE BRANCHWOOD AND UNMERCHANTABLE TIP THAT IS >3 INCHES IN DIAMETER FOR A 6-INCH UNMERCHANTABLE TIP

6-INCH TIP, > 3-INCHES

	SPECIES[2]							
D.B.H.[1]	DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
1	.0	.0	.0	.0	.0	.0	.0	.0
2	1.1	.7	.8	.9	.9	.7	1.0	.9
3	14.4	9.9	14.7	16.3	12.5	9.2	14.3	12.1
4	35	25	40	42	32	23	37	31
5	69	50	82	83	66	45	74	62
6	113	82	138	134	112	73	123	106
7	128	102	149	96	94	77	105	93
8	114	97	129	82	84	70	94	83
9	104	93	114	71	83	65	98	79
10	95	90	102	63	76	60	91	71
11	89	89	93	57	70	56	86	66
12	83	90	88	52	65	53	81	61
13	78	93	83	47	61	50	77	58
14	74	97	79	43	57	48	74	54
15	73	103	75	40	55	46	70	52
16	71	112	73	37	52	44	68	50
17	69	122	71	35	50	42	65	48
18	68	135	69	33	48	41	63	46
19	68	150	68	31	46	39	61	45
20	68	167	67	29	45	38	59	43
21	69	187	66	28	43	37	57	42
22	70	210	66	27	42	36	55	41
23	71	236	65	25	41	35	54	40
24	73	264	65	24	40	34	52	39
25	96	310	99		40	34	79	39
26	99	345	99		40	34	77	39
27	102	383	99		40	34	75	39
28	106	425	99		40	34	74	39
29	111	470	100		40	34	72	39
30	116	519	100		40	34	71	39
31	122	572	101		40	34	69	39
32	129	630	101		40	34	79	39
33	137	691	102		40	34	91	39
34	145	757	103		40	34	103	39
35	155	799	104		40	34	118	39
36	165	844	104		40	34	134	39
37	176	890	105		40	34	151	39
38	188	937	106		40	34	170	39
39	200	986	107		40	34	191	39
40	214	1040	108		40	34	214	39

TABLE 2--CONTINUED

D.B.H.[1]	SPECIES[2]							
	DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
41	229	1090	109		40	34	238	39
42	245	1140	111		40	34	265	39
43	262	1190	112		40	34	293	39
44	280	1240	114		40	34	324	39
45	299	1290	115		40	34	335	39
46	320	1350	117		40	34	346	39
47	341	1400	119		40	34	357	39
48	364	1460	121		40	34	369	39
49	389	1520	123		40	34	381	39
50	414	1570	125		40	34	394	39
51	441	1630	127		40	34	406	39
52	469	1700	129		40	34	419	39
53	499	1760	131		40	34	432	39
54	530	1820	133		40	34	445	39
55	563	1890	136		40	34	459	39
56	597	1950	138		40	34	473	39
57	633	2020	140		40	34	487	39
58	670	2090	143		40	34	501	39
59	709	2160	145		40	34	516	39
60	750	2230	148		40	34	530	39
61	792					34	545	39
62	836					34	561	39
63	882					34	576	39
64	930					34	592	39
65	979					34	608	39
66	1030					34	624	39
67	1080					34	641	39
68	1140					34	657	39
69	1200					34	674	39
70	1250					34	692	39
71	1320					34		
72	1380					34		
73	1440					34		
74	1510					34		
75	1580					34		
76	1650					34		
77	1730					34		
78	1800					34		
79	1880					34		
80	1960					34		

[1]ABOVE THE DASHED LINE, THE ENTIRE BOLE THAT IS >3 INCHES IS INCLUDED IN THE WEIGHT ESTIMATES. BELOW THE DASHED LINE, THE UNMERCHANTABLE TIP WEIGHT THAT IS >3 INCHES IS INCLUDED.

[2]DF = DOUGLAS-FIR; PP = PONDEROSA PINE; WL = WESTERN LARCH; LP = LODGEPOLE PINE; WP = WESTERN WHITE PINE; WC = WESTERN REDCEDAR; WH = WESTERN HEMLOCK; GF = GRAND FIR.

[3]OVENDRY WEIGHT.

TABLE 3--TOTAL WEIGHT OF RESIDUE PER TREE BY D.B.H., OF FOLIAGE, BRANCHWOOD (LIVE AND DEAD), AND UNMERCHANTABLE TIP FOR A 6-INCH UNMERCHANTABLE TIP

6-INCH TIP, TOTAL

	SPECIES[2]							
D.B.H.[1]	DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
1	2.9	3.2	2.4	2.1	3.7	3.8	2.8	5.0
2	12.6	12.6	10.6	12.1	13.0	13.4	12.3	18.1
3	32.5	31.6	31.4	36.6	31.4	30.4	32.5	41.6
4	64	62	66	75	61	56	66	78
5	110	104	117	129	104	90	115	128
6	170	160	185	198	164	136	181	196
7	202	207	207	173	154	156	176	206
8	204	228	194	177	154	166	181	222
9	212	254	189	187	165	180	205	247
10	224	283	188	201	170	195	219	270
11	236	311	191	211	174	209	236	290
12	252	344	196	224	181	224	255	313
13	270	380	204	240	189	242	276	339
14	290	421	214	258	199	260	300	367
15	313	466	225	279	209	280	327	396
16	338	514	238	301	221	302	355	428
17	366	567	251	325	233	325	386	461
18	395	624	267	351	247	348	419	496
19	427	685	283	379	261	373	454	533
20	461	750	300	408	276	400	491	571
21	497	819	318	440	291	427	530	610
22	534	891	337	473	307	455	571	652
23	574	968	356	507	324	484	614	694
24	616	1050	377	544	341	515	660	739
25	682	1150	436		382	570	737	806
26	727	1240	457		400	602	786	853
27	774	1330	479		419	635	836	902
28	823	1430	502		438	668	888	952
29	874	1530	526		457	703	942	1000
30	926	1630	550		478	739	998	1060
31	981	1740	575		498	776	1060	1110
32	1040	1850	601		519	813	1110	1170
33	1100	1970	627		541	852	1180	1230
34	1160	2090	654		563	891	1240	1290
35	1220	2210	682		585	932	1310	1350
36	1280	2340	710		608	973	1370	1410
37	1350	2470	739		631	1020	1440	1470
38	1420	2610	768		654	1060	1510	1540
39	1490	2750	798		678	1100	1590	1600
40	1560	2900	829		703	1150	1660	1670

TABLE 3--CONTINUED

	SPECIES[2]							
D.B.H.[1]	DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
41	1630	3040	870		740	1200	1740	1760
42	1710	3180	908		772	1250	1810	1840
43	1790	3330	946		805	1310	1890	1930
44	1870	3480	986		839	1370	1980	2020
45	1950	3630	1030		873	1430	2060	2110
46	2030	3790	1070		908	1490	2150	2210
47	2120	3950	1110		944	1550	2230	2310
48	2200	4120	1150		981	1620	2320	2410
49	2290	4280	1200		1020	1680	2410	2510
50	2380	4450	1240		1060	1750	2510	2610
51	2480	4630	1290		1100	1820	2600	2720
52	2570	4810	1330		1140	1890	2700	2830
53	2670	4990	1380		1180	1960	2800	2940
54	2770	5170	1430		1220	2030	2900	3060
55	2870	5360	1480		1260	2110	3000	3180
56	2970	5550	1530		1300	2190	3100	3300
57	3070	5750	1580		1340	2260	3210	3420
58	3180	5950	1630		1390	2340	3320	3550
59	3290	6150	1680		1430	2420	3420	3680
60	3400	6350	1740		1480	2500	3540	3810
61	3510					2590	3650	3940
62	3630					2670	3760	4080
63	3740					2760	3880	4220
64	3860					2850	4000	4360
65	3980					2940	4120	4510
66	4100					3030	4240	4660
67	4230					3120	4360	4810
68	4360					3220	4490	4960
69	4480					3310	4620	5120
70	4610					3410	4750	5280
71	4750					3510		
72	4880					3610		
73	5020					3710		
74	5160					3810		
75	5300					3920		
76	5440					4030		
77	5580					4130		
78	5730					4240		
79	5880					4360		
80	6030					4470		

[1]ABOVE THE DASHED LINE, THE ENTIRE BOLE IS INCLUDED IN THE WEIGHT ESTIMATES. BELOW THE DASHED LINE, THE UNMERCHANTABLE TIP WEIGHT IS INCLUDED. THE SOLID LINE CIRCUMSCRIBES THE FIELD DATA LIMITS, EXCLUDING THE UNMERCHANTABLE TIP.

[2]DF = DOUGLAS-FIR; PP = PONDEROSA PINE; WL = WESTERN LARCH; LP = LODGEPOLE PINE; WP = WESTERN WHITE PINE; WC = WESTERN REDCEDAR; WH = WESTERN HEMLOCK; GF = GRAND FIR.

[3]OVENDRY WEIGHT.

TABLE 4--WEIGHT OF RESIDUE PER TREE BY D.B.H., OF THAT PORTION OF THE BRANCHWOOD AND UNMERCHANTABLE TIP THAT IS >3 INCHES IN DIAMETER FOR AN 8-INCH UNMERCHANTABLE TIP

8-INCH TIP, >3 INCHES

	SPECIES[2]							
D.B.H.[1]	DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
1	.0	.0	.0	.0	.0	.0	.0	.0
2	1.1	.7	.8	.9	.9	.7	1.0	.9
3	14.4	9.9	14.7	16.3	12.5	9.2	14.3	12.1
4	35	25	40	42	32	23	37	31
5	69	50	82	83	66	45	74	62
6	113	82	138	134	112	73	123	106
7	290	157	220	207	182	153	199	172
8	415	251	312	286	264	229	284	249
9	350	298	382	241	279	216	330	259
10	316	278	337	206	248	197	302	230
11	288	261	302	180	224	181	280	208
12	265	248	276	158	205	168	260	190
13	246	239	255	141	189	157	244	176
14	230	233	237	127	176	148	229	164
15	219	230	222	115	165	140	217	154
16	208	231	210	105	155	133	206	146
17	199	234	200	97	147	126	196	139
18	191	240	191	89	140	121	187	133
19	185	249	183	83	134	116	179	127
20	180	262	177	77	129	111	172	122
21	176	277	171	72	124	107	166	118
22	172	296	167	68	119	103	160	115
23	170	317	163	64	116	99	154	111
24	169	342	159	60	112	96	149	108
25	218	408	237		112	96	213	108
26	218	440	234		112	96	207	108
27	218	475	230		112	96	202	108
28	219	514	228		112	96	197	108
29	221	556	225		112	96	192	108
30	224	603	223		112	96	188	108
31	228	654	221		112	96	184	108
32	233	709	219		112	96	191	108
33	238	769	218		112	96	200	108
34	245	833	217		112	96	211	108
35	253	874	216		112	96	223	108
36	261	917	214		112	96	237	108
37	270	961	213		112	96	252	108
38	281	1010	213		112	96	270	108
39	292	1050	212		112	96	289	108
40	305	1100	211		112	96	310	108

TABLE 4--CONTINUED

	SPECIES[2]							
D.B.H.[1]	DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
41	319	1150	211		112	96	333	108
42	333	1200	211		112	96	358	108
43	349	1250	212		112	96	385	108
44	366	1300	212		112	96	414	108
45	385	1350	212		112	96	424	108
46	404	1410	213		112	96	434	108
47	425	1460	213		112	96	444	108
48	447	1520	214		112	96	455	108
49	470	1570	215		112	96	466	108
50	495	1630	216		112	96	477	108
51	521	1690	217		112	96	489	108
52	549	1750	218		112	96	501	108
53	578	1810	219		112	96	513	108
54	608	1880	221		112	96	525	108
55	640	1940	222		112	96	538	108
56	674	2010	224		112	96	551	108
57	709	2070	225		112	96	564	108
58	746	2140	227		112	96	578	108
59	784	2210	229		112	96	592	108
60	825	2280	231		112	96	606	108
61	866				112	96	620	108
62	910				112	96	635	108
63	955				112	96	650	108
64	1000				112	96	665	108
65	1050				112	96	680	108
66	1100				112	96	696	108
67	1160				112	96	712	108
68	1210				112	96	728	108
69	1270				112	96	744	108
70	1330				112	96	761	108
71	1390				112	96		
72	1450				112	96		
73	1510				112	96		
74	1580				112	96		
75	1650				112	96		
76	1720				112	96		
77	1790				112	96		
78	1870				112	96		
79	1950				112	96		
80	2030				112	96		

[1]ABOVE THE DASHED LINE, THE ENTIRE BOLE THAT IS >3 INCHES IS INCLUDED IN THE WEIGHT ESTIMATES. BELOW THE DASHED LINE, THE UNMERCHANTABLE TIP WEIGHT THAT IS >3 INCHES IS INCLUDED.

[2]DF = DOUGLAS-FIR; PP = PONDEROSA PINE; WL = WESTERN LARCH; LP = LODGEPOLE PINE; WP = WESTERN WHITE PINE; WC = WESTERN REDCEDAR; WH = WESTERN HEMLOCK; GF = GRAND FIR.

[3]OVENDRY WEIGHT.

TABLE 5--TOTAL WEIGHT PER TREE BY D.B.H., OF FOLIAGE, BRANCHWOOD (LIVE AND DEAD), AND UNMERCHANTABLE TIP FOR AN 8-INCH UNMERCHANTABLE TIP

8-INCH TIP, TOTAL

D.B.H.[1]	SPECIES[2]							
	DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
1	2.9	3.2	2.4	2.1	3.7	3.8	2.8	5.0
2	12.6	12.6	10.6	12.1	13.0	13.4	12.3	18.1
3	32.5	31.6	31.4	36.6	31.4	30.4	32.5	41.6
4	64	62	66	75	61	56	66	78
5	110	104	117	129	104	90	115	128
6	170	160	185	198	164	136	181	196
7	364	261	278	284	242	232	270	285
8	505	382	377	380	334	325	372	388
9	459	459	456	356	362	331	437	427
10	444	470	422	344	342	332	430	428
11	435	483	399	334	329	334	429	432
12	434	502	385	331	321	340	434	442
13	437	527	376	334	317	349	443	457
14	446	557	372	342	317	360	456	476
15	459	593	372	354	320	374	473	499
16	476	634	375	369	324	391	494	524
17	495	679	381	387	331	408	517	552
18	518	730	389	407	339	428	544	583
19	544	785	398	431	349	449	573	615
20	573	844	410	456	360	472	605	650
21	604	908	423	484	372	496	639	687
22	637	977	438	514	385	522	676	725
23	673	1050	454	546	398	549	715	766
24	711	1130	471	580	413	577	756	808
25	804	1250	573		454	632	871	875
26	846	1330	592		472	664	916	922
27	890	1420	611		490	697	962	971
28	936	1510	631		510	730	1010	1020
29	984	1610	652		529	765	1060	1070
30	1030	1710	673		549	801	1110	1130
31	1090	1820	696		570	838	1170	1180
32	1140	1930	719		591	875	1230	1240
33	1200	2050	744		612	914	1290	1290
34	1260	2160	768		634	953	1350	1350
35	1320	2290	794		657	994	1410	1410
36	1380	2410	820		679	1040	1480	1480
37	1440	2540	847		703	1080	1540	1540
38	1510	2680	875		726	1120	1610	1610
39	1580	2820	904		750	1170	1680	1670
40	1650	2960	933		774	1210	1760	1740

TABLE 5--CONTINUED

D.B.H.[1]	SPECIES[2] DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
41	1720	3100	973		812	1260	1830	1830
42	1800	3250	1010		844	1320	1910	1910
43	1870	3390	1050		877	1370	1990	2000
44	1950	3540	1080		911	1430	2070	2090
45	2030	3690	1120		945	1490	2150	2180
46	2120	3850	1160		980	1550	2230	2280
47	2200	4010	1200		1020	1620	2320	2380
48	2290	4170	1250		1050	1680	2410	2480
49	2370	4340	1290		1090	1750	2500	2580
50	2460	4510	1330		1130	1810	2590	2680
51	2560	4680	1380		1170	1880	2680	2790
52	2650	4860	1420		1210	1950	2780	2900
53	2750	5040	1470		1250	2020	2880	3010
54	2850	5230	1520		1290	2100	2980	3130
55	2950	5410	1560		1330	2170	3080	3250
56	3050	5610	1610		1370	2250	3180	3370
57	3150	5800	1660		1420	2320	3290	3490
58	3260	6000	1720		1460	2400	3390	3620
59	3370	6200	1770		1510	2480	3500	3750
60	3480	6400	1820		1550	2570	3610	3880
61	3590					2650	3720	4010
62	3700					2740	3840	4150
63	3820					2820	3950	4290
64	3930					2910	4070	4430
65	4050					3000	4190	4580
66	4180					3090	4310	4730
67	4300					3180	4440	4880
68	4430					3280	4560	5030
69	4550					3370	4690	5190
70	4680					3470	4820	5350
71	4820					3570		
72	4950					3670		
73	5090					3770		
74	5220					3880		
75	5370					3980		
76	5510					4090		
77	5650					4200		
78	5800					4310		
79	5950					4420		
80	6100					4530		

[1]ABOVE THE DASHED LINE, THE ENTIRE BOLE IS INCLUDED IN THE WEIGHT ESTIMATES. BELOW THE DASHED LINE, THE UNMERCHANTABLE TIP WEIGHT IS INCLUDED. THE SOLID LINE CIRCUMSCRIBES THE FIELD DATA LIMITS, EXCLUDING THE UNMERCHANTABLE TIP.

[2]DF = DOUGLAS-FIR; PP = PONDEROSA PINE; WL = WESTERN LARCH; LP = LODGEPOLE PINE; WP = WESTERN WHITE PINE; WC = WESTERN REDCEDAR; WH = WESTERN HEMLOCK; GF = GRAND FIR.

[3]OVENDRY WEIGHT.

Residue Weight (lb) by

BASAL AREA

TABLE 6--WEIGHT OF RESIDUE PER SQUARE FOOT OF BASAL AREA BY D.B.H., OF FOLIAGE AND THAT PORTION OF THE BRANCHWOOD (LIVE AND DEAD), AND UNMERCHANTABLE TIP THAT IS ≤3 INCHES IN DIAMETER

≤3 INCHES, BASAL AREA

D.B.H.	SPECIES[1]							
	DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[2]							
1	532.8	576.6	445.8	379.2	670.2	687.7	517.1	918.1
2	531.0	543.6	449.9	512.3	555.8	583.7	518.7	788.2
3	369.1	440.9	340.6	412.8	386.4	431.6	372.0	601
4	330	419	298	377	329	379	336	535
5	296	398	253	337	281	337	302	482
6	289	396	239	327	262	318	295	460
7	276	390	215	288	224	296	266	422
8	258	375	187	272	201	275	250	397
9	246	364	169	262	186	260	243	380
10	236	353	157	252	172	247	234	363
11	224	336	147	234	158	231	227	340
12	215	323	138	220	148	218	221	321
13	208	312	132	210	139	207	216	305
14	202	303	126	201	132	199	212	292
15	196	295	122	194	126	191	209	281
16	192	289	118	189	121	185	206	271
17	188	283	115	184	116	179	204	262
18	185	277	112	180	112	174	202	255
19	182	272	109	177	109	170	200	248
20	180	267	107	174	106	166	198	242
21	178	262	105	171	103	162	197	236
22	176	258	103	169	100	159	196	231
23	174	254	101	167	98	156	194	227
24	173	250	99	165	96	153	193	223
25	172	246	99		100	157	193	225
26	170	242	97		98	154	192	221
27	169	238	96		95	151	191	217
28	168	234	94		93	148	190	213
29	166	230	93		91	146	190	210
30	165	226	92		89	144	189	207
31	164	223	91		87	141	188	205
32	163	219	90		86	139	185	202
33	162	215	88		84	138	183	200
34	160	211	87		83	136	180	198
35	159	211	87		82	134	178	196
36	158	212	86		80	133	175	194
37	157	212	85		79	131	173	192
38	156	212	84		78	130	170	190
39	155	213	83		77	129	168	189
40	154	213	83		76	128	166	187

TABLE 6--CONTINUED

D.B.H.	DF	PP	WL	LP	WP	WC	WH	GF
	SPECIES[1]							
INCHES	POUNDS[2]							
41	153	213	83		76	127	163	188
42	152	213	83		76	127	161	188
43	151	212	83		76	127	159	188
44	150	212	83		76	127	157	188
45	149	212	82		75	126	156	188
46	148	212	82		75	126	156	188
47	147	212	82		75	126	156	188
48	146	211	82		75	126	155	188
49	145	211	82		75	126	155	189
50	144	211	82		75	126	155	189
51	143	211	82		74	126	155	189
52	143	211	82		74	126	155	189
53	142	211	82		74	126	154	190
54	141	211	81		74	126	154	190
55	140	211	81		74	126	154	190
56	139	210	81		74	126	154	191
57	138	210	81		74	126	154	191
58	137	210	81		74	126	153	191
59	136	210	81		73	126	153	192
60	135	210	81		73	126	153	192
61	134					126	153	192
62	133					126	153	193
63	132					126	153	193
64	131					126	152	194
65	130					126	152	194
66	129					126	152	194
67	128					126	152	195
68	128					126	152	195
69	127					126	152	196
70	126					126	152	196
71	125					126		
72	124					126		
73	123					126		
74	122					127		
75	121					127		
76	120					127		
77	119					127		
78	118					127		
79	118					127		
80	117					127		

[1]DF = DOUGLAS-FIR; PP = PONDEROSA PINE; WL = WESTERN LARCH; LP = LODGEPOLE PINE; WP = WESTERN WHITE PINE; WC = WESTERN REDCEDAR; WH = WESTERN HEMLOCK; GF = GRAND FIR.

[2]OVENDRY WEIGHT.

TABLE 7--WEIGHT OF RESIDUE PER SQUARE FOOT OF BASAL AREA BY D.B.H., OF THAT PORTION OF THE BRANCHWOOD (LIVE AND DEAD) AND UNMERCHANTABLE TIP THAT IS >3 INCHES IN DIAMETER FOR A 6-INCH UNMERCHANTABLE TIP

6-INCH TIP, >3 INCHES, BASAL AREA

D.B.H.[1]	SPECIES[2]							
	DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
1	2.2	1.6	1.3	1.3	1.8	1.5	2.1	1.8
2	48.5	32.4	36.9	42.5	39.1	31.6	45.7	39.2
3	293.0	202.7	299.9	332.0	253.8	188.2	290.8	245.7
4	406	287	460	486	371	260	419	353
5	508	365	603	610	485	327	540	458
6	577	419	701	683	571	373	628	538
7	480	383	558	359	351	288	393	347
8	328	279	369	235	240	201	268	239
9	235	211	258	162	188	146	222	178
10	175	166	188	116	139	110	168	131
11	134	135	142	86	106	85	130	100
12	106	115	112	66	83	68	103	78
13	85	100	90	51	66	55	84	62
14	69	91	74	41	54	45	69	51
15	59	84	61	33	44	37	57	42
16	51	80	52	27	37	32	48	36
17	44	77	45	22	32	27	41	30
18	39	76	39	19	27	23	35	26
19	35	76	34	16	24	20	31	23
20	31	77	31	13	21	18	27	20
21	29	78	27	12	18	15	24	18
22	26	80	25	10	16	14	21	16
23	25	82	23	9	14	12	19	14
24	23	84	21	8	13	11	17	13
25	28	91	29		12	10	23	12
26	27	94	27		11	9	21	11
27	26	96	25		10	9	19	10
28	25	99	23		9	8	17	9
29	24	102	22		9	7	16	9
30	24	106	20		8	7	14	8
31	23	109	19		8	7	13	8
32	23	113	18		7	6	14	7
33	23	116	17		7	6	15	7
34	23	120	16		6	5	16	6
35	23	120	16		6	5	18	6
36	23	119	15		6	5	19	6
37	24	119	14		5	5	20	5
38	24	119	13		5	4	22	5
39	24	119	13		5	4	23	5
40	25	119	12		5	4	25	5

TABLE 7--CONTINUED

D.B.H.[1]	DF	PP	WL	LP	WP	WC	WH	GF
	SPECIES[2]							
INCHES	POUNDS[3]							
41	25	118	12		4	4	26	4
42	25	118	11		4	4	28	4
43	26	118	11		4	3	29	4
44	27	117	11		4	3	31	4
45	27	117	10		4	3	30	4
46	28	117	10		3	3	30	3
47	28	116	10		3	3	30	3
48	29	116	10		3	3	29	3
49	30	116	9		3	3	29	3
50	30	115	9		3	3	29	3
51	31	115	9		3	2	29	3
52	32	115	9		3	2	28	3
53	33	115	9		3	2	28	3
54	33	115	8		3	2	28	2
55	34	114	8		2	2	28	2
56	35	114	8		2	2	28	2
57	36	114	8		2	2	27	2
58	37	114	8		2	2	27	2
59	37	114	8		2	2	27	2
60	38	113	8		2	2	27	2
61	39	113	7			2	27	2
62	40	113	7			2	27	2
63	41	113	7			2	27	2
64	42	113	7			2	26	2
65	42	113	7			1	26	2
66	43	113	7			1	26	2
67	44	112	7			1	26	2
68	45	112	7			1	26	2
69	46	112	7			1	26	2
70	47	112	7			1	26	1
71	48	112	7			1		
72	49	112	7			1		
73	50	112	6			1		
74	51	112	6			1		
75	52	111	6			1		
76	52	111	6			1		
77	53	111	6			1		
78	54	111	6			1		
79	55	111	6			1		
80	56	111	6			1		

[1]ABOVE THE DASHED LINE, THE ENTIRE BOLE THAT IS >3 INCHES IS INCLUDED IN THE WEIGHT ESTIMATES. BELOW THE DASHED LINE, THE UNMERCHANTABLE TIP WEIGHT THAT IS >3 INCHES IS INCLUDED.

[2]DF = DOUGLAS-FIR; PP = PONDEROSA PINE; WL = WESTERN LARCH; LP = LODGEPOLE PINE; WP = WESTERN WHITE PINE; WC = WESTERN REDCEDAR; WH = WESTERN HEMLOCK; GF = GRAND FIR.

[3]OVENDRY WEIGHT.

TABLE 8--TOTAL WEIGHT OF RESIDUE PER SQUARE FOOT OF BASAL AREA BY D.B.H., OF FOLIAGE, BRANCHWOOD (LIVE AND DEAD), AND UNMERCHANTABLE TIP FOR A 6-INCH UNMERCHANTABLE TIP

6-INCH TIP, TOTAL, BASAL AREA

D.B.H.[1]	SPECIES[2] DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
1	535.0	578.3	447.1	380.6	672.0	689.2	519.2	919.9
2	579.5	576.0	486.7	554.8	594.9	615.3	564.4	827.4
3	662.0	643.5	640.5	744.8	640.1	619.9	662.8	846.8
4	736	706	759	863	700	639	755	889
5	804	763	857	946	766	664	841	940
6	866	814	941	1010	833	691	923	997
7	756	773	774	647	575	584	659	770
8	585	654	557	507	441	476	517	636
9	481	575	427	424	374	407	464	558
10	411	519	345	368	311	357	402	494
11	358	472	289	320	264	316	357	440
12	320	437	250	286	230	286	324	399
13	293	412	221	261	205	262	300	368
14	271	394	200	242	186	244	281	343
15	255	379	183	227	170	229	266	323
16	242	368	170	215	158	216	254	306
17	232	360	160	206	148	206	245	293
18	224	353	151	199	140	197	237	281
19	217	348	144	192	132	190	231	270
20	211	344	137	187	126	183	225	262
21	207	340	132	183	121	177	220	254
22	202	338	128	179	116	172	216	247
23	199	335	124	176	112	168	213	241
24	196	334	120	173	109	164	210	235
25	200	337	128		112	167	216	236
26	197	336	124		108	163	213	231
27	195	334	121		105	160	210	227
28	192	333	117		102	156	208	223
29	190	333	115		100	153	205	219
30	189	332	112		97	151	203	215
31	187	332	110		95	148	201	212
32	186	331	108		93	146	200	209
33	185	331	106		91	143	198	206
34	183	331	104		89	141	197	204
35	182	331	102		88	139	195	201
36	182	331	100		86	138	194	199
37	181	331	99		84	136	193	197
38	180	331	98		83	134	192	195
39	179	332	96		82	133	191	193
40	179	332	95		81	132	190	192

TABLE 8--CONTINUED

D.B.H.[1]	SPECIES[2] DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
41	178	331	95		81	131	189	192
42	178	331	94		80	130	189	192
43	177	330	94		80	130	188	192
44	177	329	93		79	130	187	191
45	176	329	93		79	129	187	191
46	176	328	92		79	129	186	191
47	176	328	92		78	129	185	191
48	175	327	92		78	129	185	192
49	175	327	91		78	129	184	192
50	175	327	91		78	128	184	192
51	175	326	91		77	128	183	192
52	174	326	90		77	128	183	192
53	174	326	90		77	128	182	192
54	174	325	90		77	128	182	192
55	174	325	90		76	128	182	193
56	174	325	89		76	128	181	193
57	174	324	89		76	128	181	193
58	173	324	89		76	128	181	193
59	173	324	89		76	128	180	194
60	173	324	88		75	128	180	194
61	173					128	180	194
62	173					127	180	195
63	173					127	179	195
64	173					127	179	195
65	173					127	179	196
66	173					127	179	196
67	173					127	178	196
68	173					128	178	197
69	173					128	178	197
70	173					128	178	198
71	173					128		
72	173					128		
73	173					128		
74	173					128		
75	173					128		
76	173					128		
77	173					128		
78	173					128		
79	173					128		
80	173					128		

[1]ABOVE THE DASHED LINE, THE ENTIRE BOLE IS INCLUDED IN THE WEIGHT ESTIMATES. BELOW THE DASHED LINE, THE UNMERCHANTABLE TIP WEIGHT IS INCLUDED. THE SOLID LINE CIRCUMSCRIBES THE FIELD DATA LIMITS, EXCLUDING THE UNMERCHANTABLE TIP.

[2]DF = DOUGLAS-FIR; PP = PONDEROSA PINE; WL = WESTERN LARCH; LP = LODGEPOLE PINE; WP = WESTERN WHITE PINE; WC = WESTERN REDCEDAR; WH = WESTERN HEMLOCK; GF = GRAND FIR.

[3]OVENDRY WEIGHT.

TABLE 9--WEIGHT OF RESIDUE PER SQUARE FOOT OF BASAL AREA BY D.B.H., OF THAT PORTION OF THE BRANCHWOOD (LIVE AND DEAD) AND UNMERCHANTABLE TIP THAT IS >3 INCHES IN DIAMETER FOR AN 8-INCH UNMERCHANTABLE TIP

8-INCH TIP, >3 INCHES, BASAL AREA

D.B.H.[1]	SPECIES[2] DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
1	2.2	1.6	1.3	1.3	1.8	1.5	2.1	1.8
2	48.5	32.4	36.9	42.5	39.1	31.6	45.7	39.2
3	293.0	202.7	299.9	332.0	253.8	188.2	290.8	245.7
4	406	287	460	486	371	260	419	353
5	508	365	603	610	485	327	540	458
6	577	419	701	683	571	373	628	538
7	1080	588	823	776	683	572	743	643
8	1190	720	893	818	755	656	815	714
9	793	675	864	545	632	488	747	586
10	579	509	617	378	455	361	555	422
11	436	395	458	272	340	275	424	315
12	337	316	352	202	261	214	331	242
13	267	259	276	153	205	171	264	191
14	215	218	222	119	165	138	215	154
15	178	188	181	94	134	114	177	126
16	149	165	150	75	111	95	147	104
17	126	148	127	61	93	80	124	88
18	108	136	108	51	79	68	106	75
19	94	127	93	42	68	59	91	65
20	82	120	81	35	59	51	79	56
21	73	115	71	30	51	44	69	49
22	65	112	63	26	45	39	60	43
23	59	110	56	22	40	34	53	39
24	54	109	51	19	36	31	47	34
25	64	120	70		33	28	62	32
26	59	119	63		30	26	56	29
27	55	119	58		28	24	51	27
28	51	120	53		26	22	46	25
29	48	121	49		24	21	42	24
30	46	123	45		23	20	38	22
31	44	125	42		21	18	35	21
32	42	127	39		20	17	34	19
33	40	129	37		19	16	34	18
34	39	132	34		18	15	33	17
35	38	131	32		17	14	33	16
36	37	130	30		16	14	33	15
37	36	129	29		15	13	34	15
38	36	128	27		14	12	34	14
39	35	127	26		14	12	35	13
40	35	126	24		13	11	36	12

TABLE 9--CONTINUED

D.B.H.[1]	SPECIES[2] DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
41	35	126	23		12	10	36	12
42	35	125	22		12	10	37	11
43	35	124	21		11	10	38	11
44	35	123	20		11	9	39	10
45	35	122	19		10	9	38	10
46	35	122	18		10	8	38	9
47	35	121	18		9	8	37	9
48	36	121	17		9	8	36	9
49	36	120	16		9	7	36	8
50	36	120	16		8	7	35	8
51	37	119	15		8	7	34	8
52	37	119	15		8	7	34	7
53	38	118	14		7	6	33	7
54	38	118	14		7	6	33	7
55	39	118	13		7	6	33	7
56	39	117	13		7	6	32	6
57	40	117	13		6	5	32	6
58	41	117	12		6	5	31	6
59	41	116	12		6	5	31	6
60	42	116	12		6	5	31	6
61	43					5	31	5
62	43					5	30	5
63	44					4	30	5
64	45					4	30	5
65	46					4	30	5
66	46					4	29	5
67	47					4	29	4
68	48					4	29	4
69	49					4	29	4
70	50					4	28	4
71	50					3		
72	51					3		
73	52					3		
74	53					3		
75	54					3		
76	55					3		
77	55					3		
78	56					3		
79	57					3		
80	58					3		

[1]ABOVE THE DASHED LINE, THE ENTIRE BOLE THAT IS >3 INCHES IS INCLUDED IN THE WEIGHT ESTIMATES. BELOW THE DASHED LINE, THE UNMERCHANTABLE TIP WEIGHT THAT IS >3 INCHES IS INCLUDED.

[2]DF = DOUGLAS-FIR; PP = PONDEROSA PINE; WL = WESTERN LARCH; LP = LODGEPOLE PINE; WP = WESTERN WHITE PINE; WC = WESTERN REDCEDAR; WH = WESTERN HEMLOCK; GF = GRAND FIR.

[3]OVENDRY WEIGHT.

TABLE 10--TOTAL WEIGHT OF RESIDUE PER SQUARE FOOT OF BASAL AREA BY D.B.H., OF FOLIAGE, BRANCHWOOD (LIVE AND DEAD), AND UNMERCHANTABLE TIP FOR AN 8-INCH UNMERCHANTABLE TIP

8-INCH TIP, TOTAL, BASAL AREA

D.B.H.[1]	SPECIES[2]							
	DF	PP	WL	LP	WP	WC	WH	GF
INCHES	POUNDS[3]							
1	535.0	578.3	447.1	380.6	672.0	689.2	519.2	919.9
2	579.5	576.0	486.7	554.8	594.9	615.3	564.4	827.4
3	662.0	643.5	640.5	744.8	640.1	619.9	662.8	846.8
4	736	706	759	863	700	639	755	889
5	804	763	857	946	766	664	841	940
6	866	814	941	1010	833	691	923	997
7	1360	978	1040	1060	907	867	1010	1070
8	1450	1100	1080	1090	956	931	1060	1110
9	1040	1040	1030	806	818	748	990	966
10	815	862	774	630	627	608	789	785
11	660	732	605	506	498	506	650	655
12	552	639	490	422	409	432	552	563
13	475	571	408	363	344	378	480	496
14	417	521	348	320	297	337	427	446
15	374	483	303	288	260	305	385	406
16	341	454	269	264	232	280	353	375
17	314	431	241	245	210	259	328	350
18	293	413	220	231	192	242	308	330
19	276	399	202	219	177	228	291	312
20	262	387	188	209	165	216	277	298
21	251	378	176	201	154	206	266	285
22	241	370	166	195	146	198	256	275
23	233	364	157	189	138	190	248	265
24	226	359	150	185	132	184	241	257
25	236	366	168		133	185	256	257
26	229	361	160		128	180	248	250
27	224	357	154		123	175	242	244
28	219	354	147		119	171	236	239
29	214	352	142		115	167	231	234
30	211	349	137		112	163	227	229
31	207	347	133		109	160	223	225
32	204	346	129		106	157	220	221
33	202	344	125		103	154	217	218
34	199	343	122		101	151	214	215
35	197	342	119		98	149	211	212
36	195	341	116		96	146	209	209
37	193	341	113		94	144	207	206
38	192	340	111		92	142	205	204
39	190	340	109		90	140	203	202
40	189	339	107		89	139	201	200

TABLE 10--CONTINUED

D.B.H.[1]	DF	PP	WL	LP	WP	WC	WH	GF
	SPECIES[2]							
INCHES	POUNDS[3]							
41	188	339	106		89	138	200	199
42	187	337	105		88	137	198	199
43	186	336	104		87	136	197	198
44	185	335	103		86	136	196	198
45	184	335	102		86	135	195	198
46	183	334	101		85	135	194	197
47	183	333	100		84	134	193	197
48	182	332	99		84	134	192	197
49	181	331	98		83	133	191	197
50	181	331	98		83	133	190	197
51	180	330	97		82	133	189	197
52	180	330	96		82	132	188	197
53	179	329	96		81	132	188	197
54	179	329	95		81	132	187	197
55	179	328	95		81	132	187	197
56	178	328	94		80	131	186	197
57	178	327	94		80	131	185	197
58	178	327	93		80	131	185	197
59	177	326	93		79	131	184	197
60	177	326	93		79	131	184	197
61	177		92			131	183	198
62	177		92			130	183	198
63	176		92			130	183	198
64	176		91			130	182	198
65	176		91			130	182	199
66	176		91			130	182	199
67	176		90			130	181	199
68	176		90			130	181	200
69	175		90			130	181	200
70	175		90			130	180	200
71	175		89			130		
72	175		89			130		
73	175		89			130		
74	175		89			130		
75	175		89			130		
76	175		88			130		
77	175		88			130		
78	175		88			130		
79	175		88			130		
80	175		88			130		

[1]ABOVE THE DASHED LINE, THE ENTIRE BOLE IS INCLUDED IN THE WEIGHT ESTIMATES. BELOW THE DASHED LINE, THE UNMERCHANTABLE TIP WEIGHT IS INCLUDED. THE SOLID LINE CIRCUMSCRIBES THE FIELD DATA LIMITS, EXCLUDING THE UNMERCHANTABLE TIP.

[2]DF = DOUGLAS-FIR; PP = PONDEROSA PINE; WL = WESTERN LARCH; LP = LODGEPOLE PINE; WP = WESTERN WHITE PINE; WC = WESTERN REDCEDAR; WH = WESTERN HEMLOCK; GF = GRAND FIR.

[3]OVENDRY WEIGHT.

Table 11--Density of wood for selected western species[1]

Species	Density
CONIFERS	Pounds per cubic feet
Cedar:	
Western redcedar	20.0
Incense cedar	23.1
Alaska cedar	27.5
Douglas-fir:	
Coastal (Washington and Oregon)	30.0
Northern Rocky Mountains	30.0
Southern Rocky Mountains	28.7
Fir:	
Grand fir	23.1
California red fir	23.7
Noble fir	24.3
Pacific silver fir	26.8
White fir	24.3
Subalpine fir	20.0
Western hemlock	28.1
Western larch	32.4
Pine:	
Lodgepole pine	25.6
Ponderosa pine	25.0
Sugar pine	22.5
Western white pine	23.7
Redwood, old-growth	25.0
Spruce:	
Engelmann spruce	21.8
White spruce	25.0
Sitka spruce	25.0
HARDWOODS	
Quaking aspen	23.7
Black cottonwood	21.8
Golden chinkapin	26.2
Tanoak	41.6
Pacific madrone	40.3
California black oak	35.6

[1]Density values for golden chinkapin from Resch and Huang (1965); for tanoak, Schniewind (1960b); for Pacific madrone, Schniewind (1960a); California black oak, Markwardt and Wilson (1935); for the rest, USDA Forest Products Laboratory (1974).

ACCURACY

For a given species and d.b.h., crown weight per tree varies considerably within individual stands. We suspect that variation in crown weight per tree may vary as much within stands as it does between major forest regions. Thus, residue predictions may be about as accurate outside as within the study areas.

Accuracy of predictions can vary considerably, depending on species, stand conditions, stand density, and accuracy of the timber stand inventory. Sources of variation include the equations used for estimating live crown weight, dead crown weight, unmerchantable tip volume, and wood density; estimates of defect and breakage factors; and accuracy of tree inventory data. The approximate half-width of the 67-percent confidence interval for live crown weight of an individual tree having mean d.b.h. expressed as a percent of the mean crown weight value for ponderosa pine is 36 percent; western larch, 38 percent; lodgepole pine ,22 percent; western white pine, 45 percent; western redcedar, 52 percent; and grand fir, 57 percent. These percentages were derived from Brown's (1978) data which were collected in western Montana and northern Idaho and had a d.b.h. range of approximately 1.0 to 35.0 inches. A study by the Forest Residues Program at the Pacific Northwest Forest and Range Experiment Station (see footnote 1, page 2) showed negligible difference between coastal and inland Douglas-fir and coastal and inland western hemlock live crown weight when this regression model was used:

$$\ln(w) = a+b \ln(d);$$

where:

w = live crown weight (pounds),
d = diameter breast height (inches), and
a and b = regression coefficients.

Based on this study, the live crown weights of trees east and west of the Cascade Range were considered the same for ponderosa pine, western larch, lodgepole pine, western white pine, western redcedar, and grand fir.

The Douglas-fir and western hemlock weights were derived from data collected from both the east and west sides of the Cascades. The d.b.h. range for western hemlock was approximately 1.0 to 46.0 inches and for Douglas-fir from approximately 1.0 to 87.0 inches. The approximate half-width of the 67-percent confidence interval for the live crown weight of an individual tree having mean d.b.h. expressed as a percent of the mean crown weight value is 89 percent for Douglas-fir and 68 percent for western hemlock. When weight is predicted for timber stands, errors for individual trees tend to balance out. Thus, estimates for stand averages are expected to be more accurate than estimates for individual trees.

A test to validate predictions was conducted in western Montana in three small stands, each dominated by a single species--ponderosa pine, Douglas-fir, or lodgepole pine. Crown weights were predicted before cutting. After cutting, the residue was intensively inventoried by the planar intersect method (Brown and Roussopoulos 1974). For residue less than 3-inch diameter, predicted weights were less than inventoried weights by 15, 22, and 37 percent of inventoried values. For all residue, predicted weights varied from 4 percent more to 15 percent less than inventoried weights. Some of the discrepancies were traced to biases in the test; thus, differences between predicted weights and actual weights should be less than indicated by our test.

The validation was done prior to skidding of any logs. This test was also repeated in a typical old-growth Douglas-fir and western hemlock stand (in the Detroit Range District, Willamette National Forest) after logging. Down woody material was intensively inventoried prior to harvesting and after the logs were skidded. A high-lead skidder was used. Because a portion of the limbs was removed from the area with the logs and small branchwood was crushed and buried in the soil and because of errors in both estimating procedures, the residue prediction overestimated by a factor of three for material less than 3 inches in diameter. This one test shows the influence of logging on the amount of residue left onsite. Local knowledge about a particular sale area, logger, and type of harvest can be used to adjust predicted weights. When residue estimates from standing trees are used, the predictions should be evaluated in relative terms. Compare areas and find out which ones are going to create the least residue and the most, and rank the other areas between them. The areas with the most potential residue should then be studied more carefuly to assure proper management. If fire assessment is made from estimates of residue from standing trees, the fire parameters should also be viewed on a relative basis.

This handbook is to be used west of the summit of the Cascade Range. Tables 3 and 8 of this handbook correspond to tables 3 and 7 of the Brown et al. (1977) handbook; if the tables in these handbooks are compared, noticeable difference in weights will be found for a given d.b.h. and species. For example, small trees in this handbook are heavier than those in Brown et al. (1977), and large trees lighter. These differences in weights are caused by (1) a paradoxical relationship between different regression functions used to obtain bole weight for small trees, (2) different height functions used in volume-to-weight calculations, and (3) significant differences in weight of dead branches between large coastal and inland trees.

Irregularities are found in the ascending flow of weights in the enclosed tables, especially from one side of the dashed line to the other. These irregularities are caused by (1) changing regression functions, (2) a rapid loss of unmerchantable tip weight as d.b.h. increases relative to the rate of increase for branchwood weight, (3) changing from estimating entire bole weights plus crown above the dashed line to estimating just unmerchantable tip weights plus crown below the dashed line, and (4) inherent data variation and sampling error.

The noticeable difference in predicted weights for small trees between this handbook and those of Brown et al. (1977) and the irregularities support the thesis that predicted crown weights should be used on a relative basis, not an absolute basis.

Land managers should be aware that a noticeable difference may be found between predicted and actual loadings. The major causes of these differences are: (1) some limbs and unmerchantable tips are hauled out of the cutting unit; (2) small twigs and foliage are buried in the soil; (3) number of trees actually cut and trampled may be different than predicted; (4) cull and breakage left onsite are difficult to predict; and (5) because of local environmental conditions, trees from a given site may have noticeably different crown weights than trees sampled to derive the enclosed weight tables. Users of residue predictions should not become discouraged by these discrepancies between predicted and actual residue loadings; by inventorying postharvest down woody material (Brown 1974, Maxwell and Ward 1976), factors may be obtained that can be used to adjust future predictions. By following this procedure, land managers will soon develop confidence in their predictions.

FUEL APPRAISAL

Appraising potential fire behavior of fuels is often termed fuel appraisal and is the process of describing fuel characteristics, such as quantity and size, and interpreting the fuel in terms of fire behavior; for example, rate of spread, fireline intensity, and flame length. Thus, the appraisal process attempts to answer the question: What is the expected fire behavior for different fuels, given steepness of slope and weather conditions? The question is difficult to answer, partly because the answer is made up of different elements of fire behavior (Anderson 1974): rate of spread, intensity, crowning potential, spotting potential, and duration of heat. One or more of these elements may have to be appraised when a specific fuel management situation is being evaluated.

Potential fire behavior of downed woody debris can be appraised by mathematical modeling and experienced judgment. Mathematical modeling of rate of spread, fireline intensity, and flame length, for example, offers the most objective means of appraising potential fire behavior. This approach may not be readily available to some land managers, however.

Experienced judgment is an important means of appraising fuels because an experienced person can integrate many factors that elude quantification. Even when more sophisticated methods are available, judgment is still important. One way of using experienced judgment is to establish a reference (tons per acre) than can be used to compare with other fuel loadings. The reference loading should represent fuels for which a consensus of land managers experienced in control of fire determines the rating. Ratings, for example, might be for low, medium, or high fire intensity potential, or either acceptable or unacceptable regarding the ability of an initial attack crew to gain control. After a reference loading is set, fuels are appraised on a relative basis. For example, for material less than 3 inches in diameter, if a loading of 10 tons per acre is established as a reference, then a loading of 20 tons per acre would exhibit approximately twice the potential fire behavior.

How Much Fuel Is Acceptable?

Fire managers commonly want to know the tonnages of fuel that are acceptable; for example, to minimize potential fire danger. This question is difficult to answer because fire behavior depends not only on fire potential at one location but also on other factors, such as distribution of fuels and fire behavior potential over surrounding areas that may cover one or more drainages. Acceptable fuel loading depends on resource values, management objectives for the land, pattern of land ownership, and suppression capability. In some stands, acceptable loading depends on resistance of trees to crown scorch and cambium kill. Professional judgment is needed to determine acceptable fuel tonnages.

Decision steps.--To decide how much fuel is acceptable requires integration of many factors (fig. 3). This can be done systematically as follows:

1. Consider management objectives and values at risk. For the latter, resource values and risk of fires causing damage during a period of high fire danger are jointly considered.

2. Appraise fuels by (a) describing fuels from inventory and prediction; and (b) interpreting fire behavior potential, such as rate of spread, flame length, intensity, and scorch height.

3. Consider other fire-related factors, such as fuel and potential fire behavior on adjoining areas, suppression capability, frequency and severity of historical fires, and fire's ecological role.

Acceptable fuel loadings can depend to a high degree on factors in item 3. For example, a heavier fuel loading would be more acceptable on a unit surrounded by sparse fuels with little chance of ignition than on a unit surrounded by heavy fuels with a high chance of ignition.

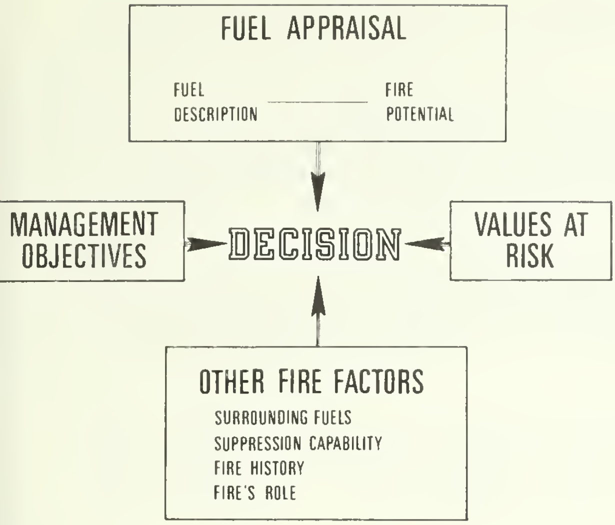

Figure 3.--Factors to consider when deciding how much fuel is acceptable.

Fuel loading standards.--No single fuel loading may be acceptable for a large administrative area. Herein lies the dilemma of setting fuel standards. Establishing standards would permit the setting of clear objectives for management of residue and provide benchmarks with which to measure accomplishments; however, standards could easily circumvent professional judgment for determining the maximum acceptable level of fuel for specific sites. One approach to determining acceptable fuel levels is to develop different standards for and evaluate each major decision for circumstances (fig. 3) encountered on a large administrative unit.

Even if fuel standards are set, the final decision on how much residue is acceptable should be coordinated among land management interests and their objectives.

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APPENDIX

The sources of the various functions used in making the weight estimates came from several investigators. For live branchwood (including foliage) weight of Douglas-fir and western hemlock, equations developed by the Forest Residues Program at the Pacific Northwest Forest and Range Experiment Station were used.[1] Hereafter, these two species will be referred to as the coastal species. For all other species, Brown's (1978) live branchwood (including foliage) weight equations are used for up to 40-inch d.b.h. At 40-inch d.b.h., a ratio was constructed between the weight of each species (except western hemlock) and the weight of coastal Douglas-fir.

$$R_i = \frac{spp_i}{DF} ;$$

where:

R_i = ratio of inland species weight to coastal Douglas-fir weight;

spp_i = species weight at 40-inch d.b.h.,

DF = coast Douglas-fir live branch weight at 40-inch d.b.h.; and

$i = 1,...,5$ species.

The ratios are shown in table 12.

Table 12--Ratios used to estimate the weight of species above 40-inch d.b.h.[1]

Species	Ratio	Range in d.b.h.
Ponderosa pine	1.95	41-60
Western larch	.54	41-60
Western white pine	.45	41-60
Western redcedar	.72	41-80
Grand fir	.99	41-70

[1]Coastal Douglas-fir is the base species.

[1]Predicting crown weight of Pacific Northwest Douglas-fir and western hemlock. Unpublished data on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Weight of coastal Douglas-fir between 41- and 80-inch d.b.h. was then multiplied by each ratio for preliminary estimates for each species. Until more data become available, this approach should give reasonable estimates.

For estimating weight of dead branchwood of coastal Douglas-fir, the equation (see footnote 1 and table 13) is used over the entire d.b.h. range (1- to 80-inch d.b.h.) of the enclosed tables. For estimating dead branchwood of other species, Brown's (1978) functions were adjusted and used. The adjustment was a ratio between Brown's (1978) Douglas-fir dead weight and each of his other species. Since this ratio was not constant over Brown's (1978) data, several ratios covering each species d.b.h. range were calculated. The ratios were then regressed on d.b.h. for each species. These regression functions were then multiplied by the coastal Douglas-fir dead branchwood weight (DFDW) function for a prediction of dead branchwood weight. The regression functions for adjustment ratios multiplied by the DFDW are shown in table 13. Beyond Brown's (1978) data, the functions flattened and were considered reasonable to use up to the d.b.h. shown in the tables for each species.

Table 13--Ratios used to adjust Brown's (1978) inland dead branchwood functions to represent the dead branchwood for each coastal species

Species	Function[1]
Coastal Douglas-fir dead weight	$DFDW = 22.46 + 0.0010X + 0.2425Y$ $X = \begin{cases} 9.8^3 & \text{if } d \leq 9.8 \\ d^3 & \text{if } d \geq 9.8 \end{cases}$ $Y = \begin{cases} d^2 - 9.8^2 & \text{if } d \leq 9.8 \\ 0 & \text{if } d \geq 9.8 \end{cases}$
Ponderosa pine	$DW = (2.11 - 0.255 \ln d)\ (DFDW)$
Western larch	$DW = 0$
Lodgepole pine	$DW = (1.927 - 1.839d^{-1.5567})\ (DFDW)$
Western white pine	$DW = (0.992 - 0.211 \ln d)\ (DFDW)$
Western redcedar	$DW = (0.97)(CDFDW)$
Western hemlock	$DW = (0.071 + 0.094 \ln d)(DFDW)$
Grand fir	$DW = (0.253 + 0.631 \ln d)(DFDW)$

[1]DFDW = coastal Douglas-fir dead branchwood weight; d = d.b.h. in inches; DW = dead branchwood weight.

Entire bole weights are estimated for trees listed above the dashed line in the tables. The boles were estimated by Faurot's (1977) total cubic-foot volume equations and converting them to weight by multiplying by the wood density of the appropriate species. Faurot (1977) studied ponderosa pine, lodgepole pine, western larch, and Douglas-fir. For other species, the Douglas-fir function was used.

Unmerchantable tip weights for trees between 6- and 24-inch d.b.h. were calculated from Faurot's (1977) equations for the unmerchantable tip. Faurot's (1977) equations for volume of unmerchantable tips and boles required d.b.h. and height as independent variables. For constructing the tables, height was estimated. For trees less than 8-inch d.b.h., height equations by Brown et al. (1977) were used; for trees above 8- inch d.b.h., the equations in table 14 were used. Data from Hartman[2] and Woodfin[3] were used to develop the equations in table 14.

Table 14--Height equations for estimating tree height (feet) for trees larger than 8-inch d.b.h.

(Model: height = a + b $(\text{d.b.h.})^{c}$)

Species	Regression coefficients a	Regression coefficients b	Regression coefficients c	Standard error	Observations	Range in d.b.h.
				Feet		Inches
Douglas-fir[1]	-30.3241	50.0770	0.3991	17.49	506	7-93
Douglas-fir[2]	-331.673	306.574	0.1346	25.07	729	10-90
Grand fir	454.834	-699.662	-0.2649	14.60	20	10-37
Shasta fir	342.965	-696.633	-0.3772	11.36	63	12-53
Silver fir	31.4377	8.9200	0.7603	14.60	39	7-28
White fir	39.2434	6.1657	0.8414	10.57	151	7-47
Ponderosa pine	261.338	-458.831	-0.4008	14.90	23	10-40
Sugar pine	60.6938	3.9472	0.8756	11.02	28	10-65
Western hemlock	1295.92	-1379.27	-0.0577	16.3	355	7-52
Incense-cedar[1]	4645.09	-4728.41	-0.0162	16.2	45	12-60
Incense-cedar[2]	3595.10	-3657.50	-0.0174	14.7	371	10-58
Port-Orford-cedar	1153.17	-1266.09	-0.0751	14.6	39	10-67
Western redcedar	-301.283	269.106	0.1427	13.5	71	10-48

[1]Data from western Oregon.

[2]Data from western Washington.

[2]Hartman, George. U.S. Department of the Interior, Bureau of Land Management, Oregon State Office, Portland, Branch of Forestry, Research and Biometrics Section.

[3]Woodfin, Richard O., USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Beyond 24-inch d.b.h., which corresponds to the end of Faurot's (1977) data, a geometric approach was used to estimate weight of the unmerchantable tip. The formula used to estimate length of the unmerchantable tip for large trees is shown below.[4]

$$T = \frac{D\,L'\,(1-A)}{1 - DA}\ ;$$

where:

T = tip length (ft),

$$D = \frac{DIB_t}{DIB_{16}}\ ,$$

DIB_t = merchantable top diameter inside bark (in),

DIB_{16} = (Girard form class)[5] *DBH,

DBH = diameter breast height (in), and

A = values used to adjust tree taper by species and d.b.h. The values used were developed by Hartman (see footnote 2) and are shown in table 15.

L' = Total height - 16 feet for butt log.

Table 15--"A" values used to estimate weights of unmerchantable tips for trees greater than 24-inch d.b.h.

Species	"A" constants[1]
Ponderosa pine and Douglas-fir	A = 0.615 - 0.00225 * d
Grand fir, western hemlock, and western white pine	A = 0.558 - 0.00225 * d
All other species	A = 0.451

[1]d = d.b.h. in inches.

[4]Rearrangement of the hyperbola formula as defined by Behre (1927).

[5]For our tables, a Girard form class of 0.72 was used.

The tip length was then put into a paraboloid formula and multiplied by density to change volume to weight:

$$TW = \left(\frac{\pi d^2 T}{8}\right) (DEN);$$

where:

TW = tip weight (lb),

d = merchantable top diameter inside bark (ft); and

DEN = wood density of species (lb/ft^3).

RESIDUE WEIGHT SUMMARY

STAND ______ LOCATION ____________ UNIT ______ DATE ________

<3 ________ ≥ 3 ________ TOTAL __________ TOP DIA. ________

Number of trees/acre from inventory by species							Crown weight/acre (pounds) by species					
DBH												

SUMMARY OF RESIDUE WEIGHT

(1) CUTTING		(2) TRAMPLING		(3) DEF. & BREAKAGE	
Pounds/acre	Tons/acre	Pounds/acre	Tons/acre	Pounds/acre	Tons/acre

PREDICTED WEIGHT, (1) + (2) + (3) Tons/acre = ________

(4) EXISTING DOWNED RESIDUE, Tons/acre = ________

TOTAL RESIDUE (1) + (2) + (3) + (4), Tons/acre = ________

Page ____ of _

GPO 990-001

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.

2. Developing and evaluating alternative methods and levels of resource management.

3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

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General Technical Report PNW-104
April 1980

2

Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America

IMPACTS OF NATURAL EVENTS

DOUGLAS N. SWANSTON

USDA FOREST SERVICE
ANADROMOUS FISH HABITAT
PROGRAM

U.S. Department of Agriculture Forest Service
Pacific Northwest Forest and Range Experiment Station

ABSTRACT

Natural events affecting vegetative cover and the hydrology and stability of a stream and its parent watershed are key factors influencing the quality of anadromous fish habitat.

High intensity storms, drought, soil mass movement, and fire have the greatest impacts. Wind, stream icing, and the influence of insects and disease are important locally.

Keywords: Anadromous fish habitat, hydrology, stability.

USDA FOREST SERVICE
General Technical Report PNW-104

INFLUENCE OF FOREST AND RANGELAND MANAGEMENT ON ANADROMOUS FISH HABITAT IN WESTERN NORTH AMERICA

William R. Meehan, Technical Editor

2. Impacts of Natural Events

Douglas N. Swanston

1980

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
Forest Service, U.S. Department of Agriculture Portland, Oregon

PREFACE

This is the second in a series of publications summarizing knowledge about the influences of forest and rangeland management on anadromous fish habitat in western North America. This paper addresses the effects on fish habitat of naturally occurring watershed disturbances and sets the scene for future discussions of the influences of human activities.

Our intent in presenting the information in these publications is to provide managers and users of the forests and rangelands of western North America with the most complete information available for estimating the consequences of various management alternatives.

In this series of papers, we will summarize published and unpublished reports and data as well as the observations of resource scientists and managers developed over years of experience in the West. These compilations will be valuable to resource managers in planning uses of forest and rangeland resources, and to scientists in planning future research. The extensive lists of references will serve as a bibliography on forest and rangeland resources and their uses for western North America.

Previous publications in this series include:

1. "Habitat requirements of anadromous salmonids," by D. W. Reiser and T. C. Bjornn.

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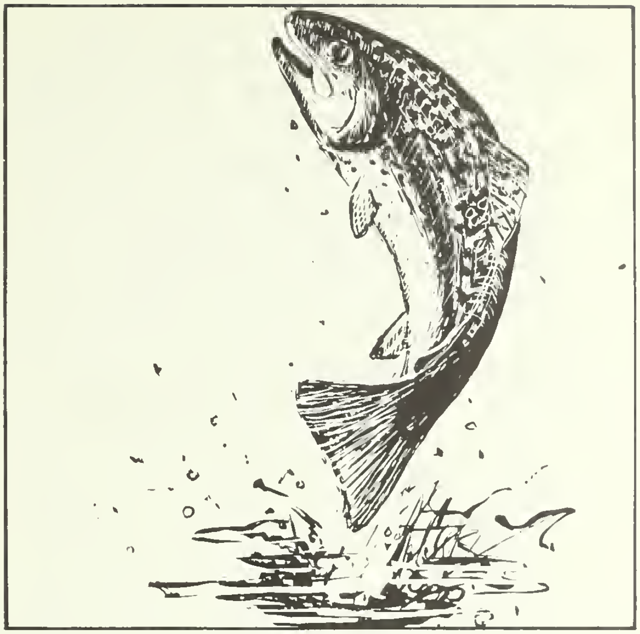


INTRODUCTION

Acceptable habitat for anadromous salmonids is the product of interaction among the geologic, climatic, and vegetative factors that control channel gradient and configuration, bottom composition, base flow, quantity and timing of maximum discharge, sediment and organic loading, and ground and overstory vegetative cover.

Under "normal" or "average" climatic conditions, those factors are in virtual equilibrium, and acceptable habitat is maintained with few or no short-term changes. Any alteration in this normal condition, however, has the potential for initiating events that may drastically alter the state of equilibrium. The result may be removal or redistribution of spawning gravels, addition of substantial quantities of sediment and organic debris, alteration of access, destruction of viable eggs and alevins, removal or redistribution of food organisms, and increased temperatures from removal of streamside vegetation.

Not all of these impacts are necessarily damaging to the habitat. For example, movement and redistribution of gravel by scour and streambed overturn may flush finer sediment from the gravels, improve access to gravel and intragravel waterflow, and create larger areas of usable spawning gravel. Stream-channel scour and excess streamflow may also remove blocking organic debris and improve access. The actual effect on habitat acceptability is largely dependent on peripheral damage to other habitat variables and on timing. Scour and streambed overturn after spawning can effectively destroy an entire generation by burial and mechanical grinding of eggs and alevins.

HYDROLOGIC IMPACTS

Seasonal and short-term changes in weather and hydrologic conditions and the amount and distribution of vegetative cover are major factors controlling streamflow and occurrence of natural events that may be damaging to anadromous fish habitat.

BASIC HYDROLOGIC PROCESSES

The quantity and timing of streamflow in anadromous fish spawning channels is largely determined by water input and the hydrologic processes operating within the contributing watershed. Harr (1976) clearly describes these hydrologic processes for small forested watersheds.

Water is introduced into the hydrologic cycle as rain, atmospheric moisture (fog), or snow. Rain falling on a watershed may reach the ground and stream surfaces directly or be intercepted by vegetation (fig. 1). Some of

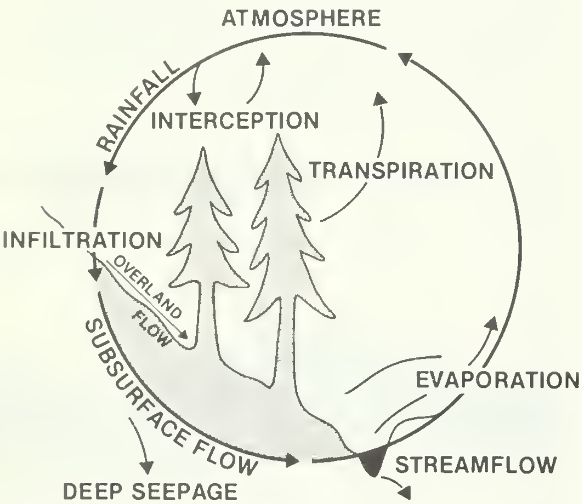


Figure 1.--Diagram of the rain-dominated hydrologic cycle (from Harr 1976).

this intercepted water evaporates; the remainder reaches the ground as stem-flow and drips through the canopy and leaf cover. The relative amount of rain "lost" to evaporation or delayed in its passage to the watershed by this interception process depends on the amount and extent of vegetative cover and the intensity and duration of the storm producing the rain. In the humid, heavily vegetated, old-growth forest areas within the influence of the Pacific storm systems, interception losses from rainfall are significant in the spring, summer, and fall when major storms are infrequent. Interception losses are substantially reduced during the winter when evapotranspiration is low and frequent high-intensity, long-duration storms occur. For example, in old-growth Douglas-fir forests in the western Cascades of Oregon, Rothacher (1963) found that nearly 100 percent of storms less than 0.13-cm (0.05-in) was intercepted and evaporated, but less than about 5 percent of storms of more than 20 cm (8 in) was intercepted and evaporated. In the drier interior areas of the West, annual rainfall is low, and high-intensity, long-duration storms are infrequent, trees are less closely spaced, and total vegetative cover may be sparse. Under these conditions, interception losses are substantially less, ranging from 5 to 14 percent of total annual rainfall (Anderson et al. 1976), but are significant in controlling the total amount of water entering a watershed. When major storms do occur, interception losses become negligible.

Snow falling on the watershed is subject to the same interception as rain and in about the same proportions (Dunford and Niederhof 1944, Rowe and Hendrix 1951, Sartz and Trimble 1956, Hart 1963). In addition, where substantial snow packs develop, water may be detained for considerable periods in its passage through the watershed and into the stream system. Snow packs contribute to such "surface storage both in the frozen phase and as free water held in the pore spaces (Anderson et al. 1976). The volume and duration of detention depend on such conditions as snow depth, air temperature, pore size and initial free water content (Corps of Engineers 1956, Smith and Halverson 1969, Smith 1974). Greatest detention is in the warm snow packs of the Sierra Nevada and the Pacific slopes of the northern Rocky Mountains where most of the water is detained over the winter and released when the snow melts. In the Cascade and Coast Ranges of

northern California, Oregon, Washington, British Columbia, and Alaska, although most precipitation occurs as rain, snow is common--particularly at higher elevations. Occasionally, a snow pack may remain for 1 to 3 months, but in most years it usually melts within 1 to 3 weeks. The highest runoff in this region has resulted from rapid snowmelt during warming trends coupled with prolonged heavy rainfall (Waananen et al. 1971, Harr et al. 1979). Watershed vegetation delays snowmelt by shading and thus extends the time that snow is held in surface storage. It also controls, to a certain extent, the rate and timing of snowmelt. Although snow under forest cover melts later and persists longer than snow in the open, it may melt more rapidly once melting begins, because melting begins later in the season when temperatures may be much higher (Anderson et al. 1976). A mixture of vegetated and open areas on a watershed may promote snowmelt at different times and reduce the total quantity released at any one time. Topography also desynchronizes melting; snow on southerly aspects may disappear before much of the snow melts on northerly aspects.

Once the water reaches the watershed floor, it infiltrates into the soil. Depending on the difference between the rate of water arrival at the soil surface and the soil's infiltration capacity or ability to allow water to enter, some water enters the subsurface and some may become overland flow. In undisturbed forests, infiltration rates of soils generally far exceed the maximum rates of rainfall so that all water enters the soil. Overland flow occurs under such conditions of vegetation, primarily as the result of limited capacity for storage, percolation, and channel expansion. Overland flow may also result from rapid addition of stored water (melting snow pack) coupled with rainfall, which together may exceed the infiltration capacity of the soil.

Upon entering the soil, water is subject to gravitational and capillary forces that cause it to move and frictional forces that tend to restrict movement. Because of the slope of most watersheds and because soil conductivity generally decreases with depth, water entering the soil begins to move downslope as it moves deeper into the soil. The direction and rate at which the water moves depend on rainfall rates and soil properties. Both rate and direction vary considerably over the course of a storm (Harr 1977). Maximum velocities of soil waterflow are low and frequently about equal to the average rate of rainfall during a storm. This slow-moving soil water is subject to evaporation and depletion by plants through the process of transpiration. The rate at which plants withdraw water is largely a function of energy available for water vaporization in leaves and the availability and ease with which water may be withdrawn from the soil. Thus, during the spring and early summer when soil water content is high and the growing season is at its peak, evapotranspiration withdrawals are high. If no additional water is added to the soil as the growing season progresses, soil moisture decreases and the remaining water becomes more tightly held by the soil. The result is a decrease in subsurface flow to the channel and a net reduction in streamflow. This condition is alleviated after the first storms in the fall recharge the soil water deficit.

In simplified terms, streamflow--on an annual or longer basis--is the difference between precipitation and evapotranspiration losses (Harr 1976). Soil moisture storage changes from time to time. Some water may

also seep deep into the subsoil and bedrock and not appear as streamflow in a small headwall basin. Generally, however, water not removed by plants ultimately moves downslope as saturated or unsaturated flow to supply streams.

As the watershed responds to rainfall, streamflow increases to a maximum known as "peak flows." Each storm hydrograph has its own peak flow, reflecting the interaction of rainfall with the physical characteristics of the watershed. High, sustained rates of rainfall contribute to greater storm runoff and higher peak flow. The magnitude of the increase in streamflow between the start of storm runoff and the peak is highly variable. It depends on the antecedent moisture content of the watershed's soils and the characteristics of the storm. Increases in streamflow of at least two orders of magnitude are not infrequent between the start and the peak of storm runoff. Maximum peak flows have resulted from rain on snow, during which a substantial portion of streamflow comes from rapid snowmelt concurrent with the downslope movement of water.

The quantity and rate at which water reaches the channel and passes through a watershed system during a particular hydrologic event is influenced by storm and watershed size and certain topographic considerations. Obviously, the larger a storm, the greater is the amount of water going into the system and the larger the potential streamflow. The influence of vegetation on streamflow resulting from small storms is greater than that from large storms because interception and evapotranspiration account for a larger proportion of small rainfalls, and soil water retained against gravity by plant roots accounts for a greater proportion of water entering the soil. As rainfall increases, these withdrawals become less important. Stormflow resulting from extreme events is minimally influenced by these withdrawal processes, although a forest cover does detain some portion of any rainstorm and thus somewhat reduces flood discharge and peak flow

Watershed size influences the quantity of streamflow and the size and timing of peak flows during any particular storm. Generally, the smaller the watershed, the more rapid are the streamflow increases in response to rainfall. For example, in small watersheds on the H. J. Andrews Experimental Forest in western Oregon, maximum rates of runoff have approached 80 percent of the average rate of rainfall for the previous 12 to 24 hours and 75 percent of the maximum 6-hour rainfall (Rothacher et al. 1967). As watersheds increase in size, total water yields increase, but peak flows and response time to storm events become somewhat reduce

Quantity and timing of local stormflow are also related to elevation. Higher elevation watersheds generally receive a larger quantity of water per storm. Because these watersheds are small, soil water retention and evapotranspirational losses are less influential and runoff and peak flows tend to be higher than in the large lower watersheds. Studies in North Carolina (Hewlett 1967) showed that forested primary ridges at 1 524 m delivered almost 457.2 mm of direct runoff per year, but forest land at lower elevations delivered only 63.5 mm. Rainfalls of 213.4 to 274.3 mm in a December storm on three watersheds above 914.4 m produced 127.0 to 223.5 mm of direct runoff and maximum peaks of 68-167 m^3/s. The rainfall on three watersheds below 91.4 m was 172.7 to 177.8 mm; direct runoff was 40.6 mm to 58.4 mm and peaks were 22 to 32 m^3/s (Hoover and Hursh 1944).

Perhaps the most important concept in understanding the

hydrology of watersheds is the variable source area of storm runoff described by Harr (1976). This concept relates storm runoff to a dynamic source area that expands and contracts according to rainfall characteristics and the capacity of the soil mantle to store and transmit water (Hewlett and Nutter 1970). Thus, as a storm progresses, the channel network expands to many times its perennial dimensions (fig. 2),

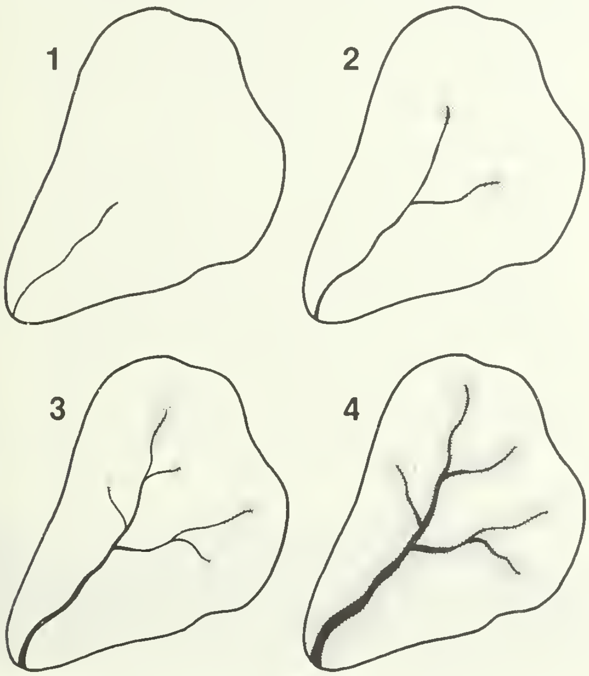


Figure 2.--Time lapse view of a small watershed showing the expansion of the channel network and source area of storm runoff (shaded area) (from Harr 1976).

and streams become both longer and wider. As a result of the variable source area of streamflow, both quantity and quality of streamflow can change drastically over a given period because the proportion of a watershed active in streamflow production changes. For sediment and organic debris, the stream represents a depository of variable surface area as well as a mode of transportation. During extreme runoff, sediment stored along the channel and debris not falling directly into the channel of the permanent stream may be subject to transport as the channel system expands.

MINIMUM FLOWS

Monthly precipitation and corresponding monthly streamflow vary greatly by season in the mountainous regions of the Northwest. The heaviest rainfall usually occurs from high-intensity storms during the late fall and winter in the Pacific coastal mountains and during the late spring along the west slope of the Rocky Mountains.

Extended dry weather is infrequent in the northern portions of the Pacific coastal mountain system (Washington, British Columbia, and Alaska). In these areas, rainfall is sufficiently frequent throughout the year to maintain adequate streamflow even during the summer. Elsewhere in the forested regions of the Northwest, extended summer drought is common; most of the annual precipitation occurs during the late fall and early spring storms. In such areas, minimum streamflows occur during the late summer and early fall and may be 1,000 to 5,000 times smaller than maximum peak flows in winter. Flow may cease entirely in many first-order streams (Harr 1976).

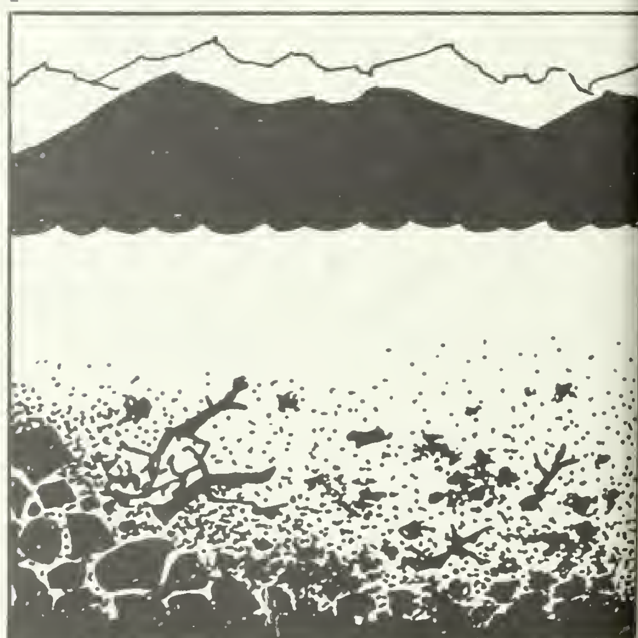
During low-flow periods, soil moisture is at its lowest because water has been removed by evapotranspiration and slow subsurface drainage to streams. Storms are infrequent and small; a large proportion of rainfall, when it occurs, is intercepted by forest vegetation and evaporates, with little water reaching the soil. Any storm runoff results almost entirely from channel interception, and peak flows are extremely small. The net result is that streams have little capacity to move sediment or transport debris. Streamflow is maintained by slow drainage from local ground-water sources or isolated saturated zones. Streamflow is at a very low rate, and stream network divisions are at annual minimums. First-order channels have no flow, and higher

order channels are short, with flow occupying only a small part of their widths. Flow may consist of a slow trickle between relatively isolated pools. Under these conditions, large areas of stream gravel are exposed; intragravel water movement is reduced and limited to considerable depths below the surface. During droughty periods, the potential for fire in the surrounding vegetation is also greatly increased.

MAXIMUM FLOWS

Storms of high intensity or long duration in undisturbed watersheds cause increased peak flows and local flooding, frequently resulting in accelerated mass soil movement, streambank erosion, and surface erosion of nonvegetated areas with attendant increases in sediment discharge to the channel[1/] (Rothacher 1959, 1973; Anderson 1975; Fredriksen et al. 1975). Patton and Baker (1976) have defined flash flood or high peak-flow potential in drainage basins by a regional indexing technique computed as the standard deviations of the annual maximum streamflows. Basins with high flash-flood potential tend toward greater relief and greater drainage densities combined with steep hillslopes and stream-channel gradients. These are characteristics of the majority of the Pacific Coast anadromous fish stream and river systems.

In the heavily forested Pacific coastal mountain systems, highest peak flows come during the late fall and winter as a result of heavy rainfall on wet soil mantles. At lower elevations, these peak flows are produced almost entirely by high-intensity rainstorms. Within the snowpack zone, both rain alone and warm rain on snow associated with warming temperatures are important generators of peak flow. In western Oregon, peak flows during major winter storms may be as much as 100 times greater than flows immediately before such storms.[1/] Comparable increases can be postulated for the rest of the Pacific coastal mountain belt based on the similarity in intensity and frequency of storms throughout the region. Along the west slopes of the Rocky Mountains, peak flows develop during the spring as a result of melting snow and occasionally as the result of upslope or convective storms, which dump large quantities of rain in the foothills during May and June (Anderson 1975). If snowmelt and storm rainfall are synchronized, substantial increases in peaks and accompanying flooding are produced (Goodell 1959).



SEDIMENT AND ORGANIC DEBRIS LOADING

Heavy sedimentation of streams and channel damage from flood flow and soil mass movements are closely linked to the pulsing action of streamflow caused by fall and winter storm fronts from the

[1/] *Unpublished report, "Forest practices and streamflow in western Oregon," by R. D. Harr. Paper presented at Symposium on Watershed Management, Am. Soc. Civ. Eng., Logan, Utah, 1975.*

Pacific Ocean and by the rapid snowmelt and upslope convective storms generated in the interior mountain areas. Streams rise and fall rapidly in relation to precipitation, storm duration, snowmelt, and the amount of water already in the soil.

The suspended sediment content of stormflow generally lags behind the storm hydrograph, with the highest sediment concentrations in transport occurring as streamflow increases to its peak. Sediment transported during these stormflow periods can be substantial. Mean annual concentrations of sediment from undisturbed watersheds are relatively low. For example, Fredriksen et al. (1975) reported mean annual concentrations of sediment for undisturbed watersheds in the western Cascades of Oregon and in the Oregon Coast Ranges from 1.3 to 44.6 mg/l and from 1.4 to 21.4 mg/l, respectively. This contrasts sharply with mean maximum increases in concentration occurring primarily during stormflow, which ranged from 11 to 52 times the mean annual rate for the western Cascades watershed and from 39 to 83 times the mean annual rate for the Coast Ranges watershed. Much of this increase is the direct result of soil mass movements into the stream channels and mobilization of sediment temporarily stored within or along the channel margins.

Large organic debris deposited and redistributed during stormflow and soil mass movements is a common and important channel feature, with both physical and biological consequences to anadromous fish habitat.

Most often debris--including material resulting from fire, disease, and decomposition--is delivered to the stream by a combination of processes including windthrow, streambank undercutting, and soil mass movements. Once in the stream, it may be deposited almost immediately in or along the channel margins or transported for considerable distances down the channel to be deposited as windrows of small organic detritus and piles or jams of mixed logs and smaller organic debris. The point of deposition and the distance of travel depend largely on the originating-process and the volume of streamflow in the channel at the time of deposition. Streams of all sizes are affected by debris, but loading tends to decrease as stream width increases. In small headwater channels, trees generally lie where they fall and are only moved as a result of decomposition or by catastrophic events, such as extreme stormflow or debris torrents.[2/] As streams within a watershed expand in response to storm runoff, they become wider and deeper. Large organic material may float and accumulate at channel obstructions, forming debris accumulations or debris dams. In rivers, where a tree bole of any size can be floated, large organic debris usually accumulates at bends or along the channel margin as a result of high flow (Swanson et al. 1976).

Large jams can block the passage of migrating fish and effectively close areas to spawning (Meehan 1974). In addition, such jams may form a temporary base level for the affected channel, resulting in deposition on the upstream side and extensive scour downstream. If the jam is large enough, the stream may form a new channel, causing extensive bank erosion and effectively bypassing the jam and sections of spawning gravels downstream. In headwater streams, debris torrents and extreme stormflows carry large amounts of wood through the system causing extensive scour, redistribution of stream gravels, and damage to culverts, roads, and bridges.[2/]

[2/] *Manuscript in preparation, "Some management impacts of organic debris in Pacific Northwest streams," by F. J. Swanson and G. W. Lienkaemper. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.*

Debris accumulations in small- to medium-sized streams (third- and fourth-order) often trap gravel that may provide excellent spawning habitat for anadromous fish. Also, fine sediment trapped by debris in headwater streams is routed through the system slowly as the wood accumulations decompose. Wood in small streams frequently provides a "steepened channel profile," in which much of the drop in the stream is over wood-created falls alternating with longer, low-gradient pools. This gives a large portion of the stream a lower gradient than the overall stream channel.

The biological community can benefit from such stream debris. Debris accumulations provide cover for resident and anadromous fish (Narver 1971, Hall and Baker 1975), while serving to retain detritus entering the stream system. Before detritus feeders find detritus of terrestrial origin palatable, it must be conditioned by the microbes in the stream (Triska and Sedell 1975). Debris accumulations keep the conditioned detritus, the insects that eat it, and the fish that eat the insects all in the same area.

MASS SOIL MOVEMENT

Increased water in the soil--both seasonal and during storm periods--produces saturated soil and a rising water table on steep slopes, frequently initiating soil mass movements that transport large volumes of sediment and organic debris into and through the channel systems. Such processes add substantial quantitie of sediment and organic debris to the stream channels over short periods (minutes, hours, days), causing channel alteration, rapid increases in bed and suspended load siltation of gravels, and partial or complete blocking of the stream channel through debris-dam formation. If entry velocities and channel gradient are high enough, the tremendous bulking effects of contained soil, rock, and organic debris commonly scour the channel below the point of entry, removing and redistributing bottom gravels and destroying substantial portions of the streamside vegetation.

The mechanics of failure, type of soil mass movement, and the factors controlling and contributing t development of soil mass movements on forested terrain are well described in the literature (Bishop and Stevens 1964; Swanston 1967, 1969, 1971, 1974, Swanston and Swanson 1976). Three groups of processes have a major impact on habitat.

SLUMP-EARTHFLOWS

Earthflow processes (fig. 3) are for the most part slow moving; where they intersect a stream, they provide continuous long-term sources of sediment to the channel. Measured rates of movement in Oregon and northern California, where these processes are most common, range from 2.5 cm/year to as high as 2 720 cm/year with the higher rates predominantly occurring along the major anadromous fish rivers draining the northern California Coast Ranges (table 1). Based on studies of 19 earthflows entering the Van Duzen River basin in northern California, Kelsey (1978) estimated that the total

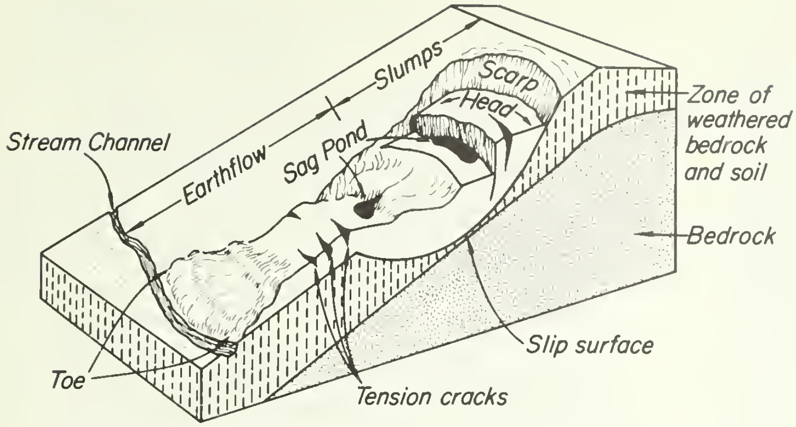


Figure 3.--Diagram of a typical slump-earthflow developed in deeply weathered bedrock and surficial materials. Slumping is the backward rotation of a block of soil along a curved failure surface with little downward displacement. Earthflows usually begin with a slump or series of slumps and, through a combination of true rheological flow of the clay fraction and slumping and sliding of individual blocks, move downslope with a continuity of motion resembling the flow of a viscous fluid.

Table 1--Rates of movement of active earthflows in the western Cascade Range, Oregon (Swanston and Swanson 1976), and Van Duzen River basin, northern California (Kelsey 1978)

Location	Period of record	Movement rate	Method of observation
	Years	Cm/yr	
Landes Creek[1] (Sec. 21, T.22 S, R.4 E)	15	12	Deflection of road
Boone Creek[1] (Sec. 17, T.17 S, R.5 E)	2	25	Deflection of road
Cougar Reservoir[1] (Sec. 29, T.17 S, R.5 E)	2	2.5	Deflection of road
Lookout Creek[1] (Sec. 30, T.15 S, R.6 E)	1	7	Strain rhombus measurements across active ground breaks
Donaker Earthflow[2] (Sec. 10, T.1 N, R.3 E)	1	60	Resurvey of stake line
Chimney Rock Earthflow[2] (Sec. 30, T.2 N, R.4 E)	1	530	Resurvey of stake line
Halloween Earthflow[2] (Sec. 6, T.1 N, R.5 E)	3	2 720	Resurvey of stake line

[1]Swanston and Swanson 1976.

[2]Kelsey 1978.

sediment discharge to the river by earthflow processes between 1941 and 1975 was 1 409 500 m^3. This is equivalent to an annual yield of 41 455 m^3 or about 2 182 m^3 per failure. In contrast, studies at Lookout Creek in the western Cascades of Oregon showed annual movement rates of only 10 cm/year (Swanston and Swanson 1976), with estimated annual yields from a single earthflow of only 340 m^3.

Earthflow movement is predominantly seasonal--with most movement occurring after fall and winter rains have thoroughly wetted the slopes--although movement may be continuous in areas where groundwater maintains the water content of the moving mass.

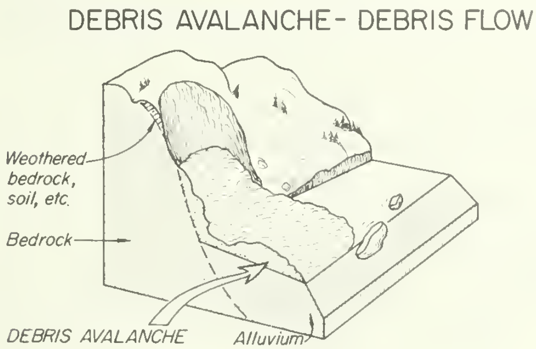
During periods of movement, the individual earthflow toe protrudes into the channel and is gradually eroded away by high winter flows. Slumping (fig. 4), from the undercutting of the protruded material by stormflow, may abruptly add large quantities of soil, rock, and organic debris to the channel. If flows are high enough, this soil and some of the finer organic debris may be transported out of the system almost immediately to be distributed downstream as blankets and windrows of sediment and organic material. The larger rock and organic debris may remain behind as a residual "lag," forming a tangled mass of rocks and logs behind which gravels and sediment from up-channel may accumulate. This lag frequently creates a sharp increase in channel gradient through the accumulation zone.

Figure 4.--The "Drift Creek Slide" in the west-central Coast Ranges of Oregon, a slump in nearly horizontal sandstone and siltstone. The lower end has been transformed into an earthflow and has dammed Drift Creek to form a lake more than 12 meters deep.

DEBRIS AVALANCHES AND DEBRIS FLOWS

Debris avalanches, flows, and torrents constitute the most damaging of the soil mass-movement processes to anadromous fish habitat. Debris avalanches and debris flows (fig. 5A and B) are rapid, shallow mass movements that develop on steep hillsides and generally contribute 60 percent or more of their initial failure volume almost immediately to the channel. Debris avalanches generally grade into debris flows as water content of the sliding mass increases.

A



B

Figure 5.--Debris-avalanche debris-flow failures. Debris avalanches are rapid downslope movements of soil, rock, and organic debris, which generally grade into debris flows as water content of the sliding mass increases: A, Diagram of typical debris avalanche or debris flow in shallow, semi-cohesionless soils; B, massive debris avalanche developed in granite-derived soils near Wrangell, Alaska.

Debris avalanches have rather consistent characteristics in the various geologic and geomorphic settings from northern California to southeast Alaska and eastward into the Idaho batholith country (Bishop and Stevens 1964; Dyrness 1967; Swanston 1970, 1974; Gonsior and Gardiner 1971; O'Loughlin 1972; Colman 1973; Fiksdal 1974). In all these areas, debris avalanches are usually triggered during high-intensity storms. For example, in the H. J. Andrews Experimental Forest, Oregon, storms of a 7-year or less return period initiate debris avalanching in forest areas. Swanston (1969) has correlated storms with a 5-year return interval with accelerated debris avalanching in coastal Alaska.

Debris avalanches leave scars as spoon-shaped depressions with long tails extending downslope toward the channel, from which less than 10 to as much as 10 000 m^3 of soil and organic debris have been transported. Average volumes of individual debris avalanches in forested areas in the Pacific Northwest range from about 1 540 to 4 600 m^3. Areas prone to debris avalanches are typified by shallow, low-cohesion soils on steep slopes where subsurface water may be concentrated by subtle topography on impermeable bedrock or glacial till surfaces. Because debris avalanches are shallow failures, factors such as timber and other vegetation (which control root-anchoring effects and transfer of wind stress to the soil mantle, as well as rate of water supply to the soil during rainfall and snowmelt) have significant effect on where and when debris avalanches occur. An added factor in areas of even occasional seismic activity is the lateral stress applied to the soil mantle by ground shaking during earthquakes. Seismic activity has been noted as a factor contributing to soil mass-movement initiation in Alaska

(Bishop and Stevens 1964) and in the central Rocky Mountains (Bailey 1971). In the Queen Charlotte Islands, British Columbia, which is noted as the most seismically active area in Canada (Sutherland-Brown 1968), a direct correlation with high soil mass-movement activity has been postulated by Alley and Tomson (1978).

The rate of occurrence is controlled by stability of the landscape and the frequency of storms severe enough to trigger them. Swanston and Swanson (1976 and table 2) report annual rates of debris-avalanche erosion from six forested study sites in Oregon, Washington, and British Columbia, ranging from 11 to 72 m^3/km^2 per year.

Table 2--Debris-avalanche erosion in forest, clearcut, and roaded areas (Swanston and Swanson 1976)

Site	Period of record	-----Area-----		Slides	Debris-avalanche erosion	Rate of debris-avalanche erosion relative to forested areas
	Years	Percent	Km^2	Number	$M^3/(km^2 \cdot yr)$	
Stequaleho Creek, Olympic Peninsula, Washington (Fiksdal 1974)						
Forest	84	79.0	19.3	25	71.8	1.0
Clearcut	6	18.0	4.4	--	--	--
Road	6	3.0	.7	83	11 825.0	165.0
			24.4	108		
Alder Creek, western Cascade Range, Oregon (Morrison 1975)						
Forest	25	70.5	12.3	7	45.3	1.0
Clearcut	15	26.0	4.5	18	117.1	2.6
Road	15	3.5	.6	75	15 565.0	344.0
			17.4	100		
Selected drainages, Coast Mountains, S.W. British Columbia						
Forest	32	83.9	246.1	29	11.2	1.0
Clearcut	32	9.5	26.4	18	24.5	2.2
Road	32	1.5	4.2	11	[1]282.5	25.2
			276.7	58		
H. J. Andrews Experimental Forest, western Cascade Range, Oregon (Swanson and Dyrness 1975)						
Forest	25	77.5	49.8	31	35.9	1.0
Clearcut	25	19.3	12.4	30	132.2	3.7
Road	25	3.2	2.0	69	1 772.0	49.0
			64.2	130		

[1]Calculated from O'Loughlin (1972, and personal communication), assuming that area of road construction in and outside clearcuttings is 16 percent of the area clearcut. Colin L. O'Loughlin is now at Forest Research Institute, New Zealand Forest Service, Rangiora, New Zealand.

When a debris avalanche occurs, large quantities of soil, rocks, and organic debris are dumped directly into the channel. Because debris avalanches occur primarily during high stormflow, a large part of the soil and organic debris is transported almost immediately away from the entry point to be deposited downstream as blankets and windrows. Boulders and large organic debris remaining at the entry point may temporarily dam the channel and cause an increase in channel gradient for a variable distance downstream.

DEBRIS TORRENTS

Debris torrents are the rapid movement of water-charged soil, rock, and organic debris down steep stream channels (fig. 6). Debris torrents typically occur in steep, intermittent, first- and second-order channels. These events are triggered during extreme stormflow by debris avalanches from adjacent hillslopes, which enter a channel and move directly downstream, or by the breakup and mobilization of debris accumulations in the channel. The initial slurry of water and associated debris commonly entrains large quantities of additional inorganic and living and dead organic material from the streambed and banks. Some torrents are triggered by debris avalanches of less than 100 m^3, but may ultimately include 10 000 m^3 of debris entrained along the track of the torrent. As the torrent moves downstream, hundreds of meters of channel may be scoured to bedrock (fig. 7). When the torrent loses momentum, a tangled mass of large organic debris is deposited in a matrix of sediment and fine organic material covering areas up to several hectares (Swanston and

Figure 6.--Debris torrent developed in pumice on the north slope of Entiat Valley, east-central Cascades, Washington. Torrent developed as the result of temporary damming of the stream at near peak flow by debris avalanches along the channel slopes.

Figure 7.--Channel scoured to bedrock by debris torrent passage in the Oregon Coast Ranges.

Swanson 1976, and fig. 8). The main factors controlling the occurrence of debris torrents are the quantity and stability of debris in channels (supplied by earlier debris avalanches and debris torrents), steepness of channel, stability of adjacent hillslopes, and peak-discharge characteristics of the channel. The concentration and stability of debris in channels reflect the history of stream flushing and the health and stage of development of the surrounding timber stand (Froelich 1973).

Figure 8.--Debris jam in an anadromous fish stream in the Oregon Coast Ranges. The jam resulted from a debris torrent entering the stream from an adjacent slope.

Although debris torrents pose significant hazards to anadromous fish habitat, they have received little study (Fredriksen 1963, 1965; Morrison 1975; Swanson et al. 1976). Velocities of debris torrents, estimated to be up to several tens of meters per second, are known from only a few spoken and written accounts. The rates of occurrence of torrents have been systematically documented in only two small areas of the Pacific Northwest, both in the western Cascade Range of Oregon (Morrison 1975, Swanston and Swanson 1976). In these studies rates of debris-torrent occurrences were observed to be 0.005 and 0.008 event per square kilometer per year for forested areas (table 3). Torrent tracts initiated in forested areas ranged from 100 to 2 280 m and averaged 610 m of channel length. Debris avalanches played a dominant role in triggering 83 percent of inventoried torrents (Greswell et al. 1979). Mobilization of stream debris not immediately related to debris avalanches (debris-dam failure within the channel) has been an important local factor in initiating debris torrents in headwater streams (Swanston 1969).

WIND

Strong winds, primarily during storms, frequently uproot trees, which drastically disturbs forest soils and may effectively alter the immediate channel environment.

Windthrow has been recognized for many years as a widespread natural phenomenon in forested regions throughout the United States (Shaler 1891, Holmes 1893, Van Hise 1904, Lutz and Griswell 1939, Stephens 1956). Storms with winds of hurricane force may cause an entire stand to be uprooted; more commonly, however, scattered

Table 3--Debris-torrent occurrence for selected areas in western Oregon

(Swanston and Swanson 1976)

Site	Area of watershed	Period of record	Debris torrents triggered by debris avalanches	Debris torrents with no associated debris avalanche	Total		Rate of debris-torrent occurrence relative to forested areas
					No.	No./km^2/yr	
H. J. Andrews Experimental Forest, western Cascade Range, Oregon[1]							
Forest	49.8	25	9	1	10	0.008	1.0
Clearcut	12.4	25	5	6	11	.036	4.5
Road	2.0	25	17	--	17	.340	42.0
	64.2		31	7	38		
Alder Creek drainage, western Cascade Range, Oregon							
Forest	12.3	90	5	1	6	.005	1.0
Clearcut	4.5	15	2	1	3	.044	8.8
Road	.6	15	6	--	6	.667	133.4
	17.4		13	2	15		

[1] Frederick J. Swanson, unpublished data, on file at Forestry Sciences Laboratory, USDA Forest Service Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon.

individuals or groups of trees are knocked down (fig. 9). In the Pacific Northwest and along the North Pacific coast, windthrow is an important initiator of soil mass movement and, excluding soil mass-movement activity, is probably the most significant natural phenomenon providing organic materials to the stream system.

Figure 9.--Natural windthrow along Kook Creek, Chichagof Island, southeast Alaska.

Studies of windthrow in virgin forests of the Oregon Coast Ranges (Ruth and Yoder 1953) 1953) indicate it is most severe on areas with a high water table or very shallow soils. Windthrow on such forested slopes tends to open the mineral soil to direct ingress of water, destroys the anchoring and reinforcing effect of tree roots on unstable sites, and--if windthrow occurs on a section of slope at or near saturation--may initiate soil mass movement directly through impact and instantaneous pore-water pressure development (Swanston 1967). Windthrow has been identified directly as the probable initiating cause of debris avalanches in coastal Alaska (Swanston 1967) and the central Oregon Coast Ranges, and it is believed to be a contributor to debris-avalanche development in the western Cascades (Swanson and Dyrness 1975).

Windthrow adjacent to channels adds large organic debris directly to them and may open large sections of the stream to direct sunlight. Large organic debris in streams (logs and branches) may create debris dams, allowing gravel and fine sediment to accumulate from upstream, at least as long as the dam remains in place. Such dams may be removed during stormflows or, if the dam remains in place, may cause local flooding or alteration of the channel to bypass the obstruction. The exposure of the channel to direct sunlight may increase water temperatures in that section during the summer, and the lack of insulating canopy may decrease winter temperatures.

INSECTS AND DISEASE

The killing of trees by insects and disease affects the forest and ultimately the stream environment much the same as windthrow. Interception and evapotranspiration are

reduced or stopped, but infiltration is usually not affected (Anderson et al. 1976). Because of the loss of overhead cover near stream channels, water temperature may be locally increased and water chemistry altered temporarily by leaf fall and accumulation of organic vegetation in channels. The weakened root systems in dead trees also make the affected timber much more susceptible to windthrow (with its accompanying soil disturbance and accumulation of large organic debris in channels). Although no direct data are available, the destruction of viable root systems on unstable slopes by these epidemics would greatly reduce the slopes' ability to resist failure when soil water content is high and in periods of stormflow.

Forest Service data (USDA Forest Service 1958, 1975) indicate that insects kill far more trees than disease does. Damage from insect and disease infestation is scattered. Mortality in any given area is usually confined to a single tree species and not all the individuals of that species are infested. In mixed forest types, this has practically no impact on erosion and streamflow because living forest cover and its attendant root systems are maintained. Under those conditions, the only damage to the stream environment might be from death of streamside trees, which would open the channel to direct sunlight and increase organic debris loading.

Occasionally, large areas do become infested, and substantial portions of the timber cover are destroyed. On the White River drainage in Colorado (Love 1955, Bethlahmy 1974), bark beetles killed most of the trees in a 1 974-km^2 area with a resultant increase in total streamflow of about 22 percent over the next 25 years. Peak flows were 27 percent higher. The actual impacts on the channel system are unknown.

FREEZING AND ICE FORMATION

In northern latitudes, freezing temperatures and development of ice on hillslopes and within stream channels may substantially reduce rate of streamflow and increase sediment contributions from bare hillslope areas under certain conditions. If the channel freezes over, ice formation and subsequent melting and breakup may result in flooding and extensive bank and channel erosion by mechanical plowing and formation of "anchor ice."

In areas where extensive channel-ice formation is rare, freezing temperatures tend to have their greatest impact on accelerated discharge of surface sediment to the channel.

"Concrete frost"--wet soil solidly frozen--probably occurs only sporadically on forested slopes in the interior areas of the Northwest (Anderson et al. 1976). In the Pacific coastal mountains, it is generally absent. Where present, it may prevent infiltration and cause local overland flow; its

frequency is so low, however, that it probably has very little effect on water in the channel. Much more important in terms of soil freezing effects is the development of "needle ice." Needle ice is produced by the growth of frost crystals beneath pebbles and soil particles on unvegetated slopes during diurnal cycles of freezing and thawing (Sharpe 1960). The particles are lifted perpendicular to the slope surface; when the needle ice begins to melt, the ice crystals and their load of earth, pebbles, and organic debris fall downslope and may continue to slide and roll for some distance. Such "surface creep" is an important local contributor to sediment transport from bare mineral soil areas to stream channels throughout the mountainous areas of Western North America.

In areas where extensive channel ice is formed, freezing results in supercooling of the water, nucleation of "frazil ice" particles (spicules and thin plates of ice formed in supercooled, turbulent waters) and formation of anchor ice around stones and gravel particles along the channel bottom (Michel 1973, Gillfilain et al. 1973). Static ice begins to form along the stream banks in areas of nonturbulent flow. Through accumulation of frazil ice along the rough streamward edges of the static ice, slush and ice flows eventually form a continuous ice cover. Anchor ice forms along the channel bottom from the accumulation of frazil ice particles on the rough surfaces of coarse bottom sediments and on the lee sides of pebbles, rocks, and boulders. During ice formation, anchor ice frequently breaks loose from the bottom and is carried to the surface or downstream, with gravel and coarse bottom sediments still adhering. The result may be an extensive redistribution and downstream transport of bottom materials.

In small streams used by anadromous fish in the arctic and subarctic, such ice formation diverts a substantial volume of water from winter streamflow and results in rapid transport of channel sediment downstream. Kane and Slaughter (1973) have estimated that winter icing of Gold Stream--a stream near Fairbanks, Alaska, that is used by anadromous fish--accounts for nearly 40 percent of the winter streamflow.

The breakup of ice cover in the spring generally follows ablation of the seasonal snowpack when rising water in the channel causes cracking of the ice from vertical hydrostatic pressures, and the resultant blocks and plates of ice are carried downstream as ice floes. The movement of these floes is intermittent and jerky, resulting in periodic damming and flooding of low areas near the channel, extensive gouging and mechanical erosion of the channel banks, and sedimentation and redistribution of bottom gravels.

FIRE

Burning of forests destroys the covering vegetation on slopes

and along stream channels and may locally alter the physical properties of the surface layers of soil. The immediate impact is to increase both water yield and stormflow discharge from the watershed. Fire also exposes the bare mineral soil to increased surface runoff and erosion. Surface runoff from burned areas generally increases dissolved nutrient transport and loading of the channel systems. Surface erosion processes--including raindrop and rill erosion and dry ravel during wetting/drying and freezing/thawing cycles--transport large volumes of sediment and debris from the watershed slopes to the channel (fig. 10). From 1 to 5 years afterward, fire may increase the potential for accelerated landslide activity through decay of anchoring and reinforcing root systems (Bishop and Stevens 1964, Swanston 1974, Ziemer and Swanston 1977.

Intensive drying of soil, combustion of organic matter that binds soil aggregates, loss of litter cover, and strong convective winds produced by the fire's heat all contribute to debris movement down steep slopes during hot fires. In steep terrain, rolling rocks and logs released by burning of roots and other supportive organic matter trigger downslope movement of additional material, greatly increasing concentration of large woody debris on slopes and within stream channels.[3] Hydrophobic (water repelling) soils have been reported in a great variety of ecosystems after wildfire and slash fires (DeBano 1969, DeByle 1973, Megahan and Molitor 1975, Dyrness 1976, Campbell et al. 1977). The relative importance of this phenomenon

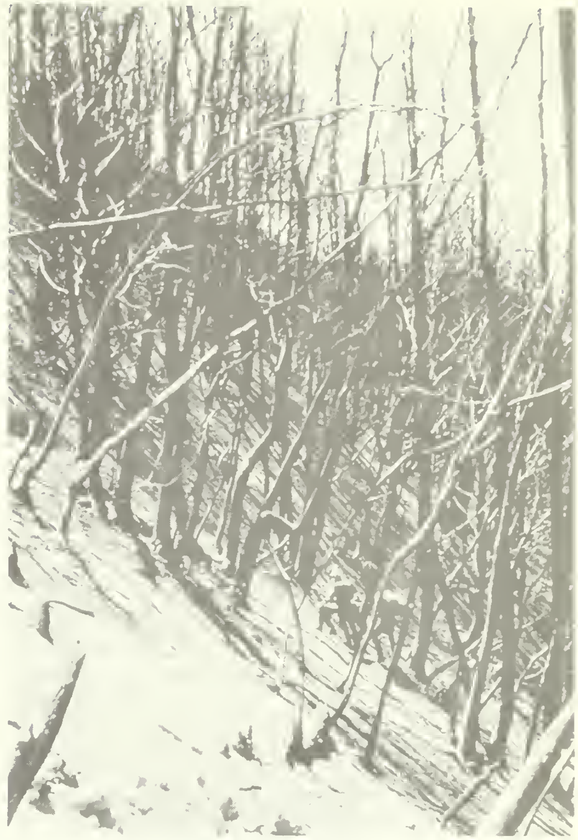


Figure 10.--Dry ravel, or dry creep and sliding, of surface materials downslope after a fire along the Klamath River in northern California.

on increased rill, sheet, and soil mass-movement erosion commonly observed after intense fire has not been well documented. Hot ground fire can reduce water storage capacity of surface organic matter (Dyrness et al. 1957). Reduced interception and evapotranspiration may result in decreased summer drawdown of soil water by vegetation (Klock and Helvey 1976a), although sometimes, as in heath vegetation, water loss can increase when the soil surface is exposed (C. H. Grimingham, Univ. of Aberdeen, personal communication). Effects of reduced interception and evapotranspiration may be offset in part by increased overland flow in response to reduced infiltration from loss of litter layer, development of hydrophobic soil, compaction by raindrops, plugging of pores by fine soil

[3] *Manuscript in preparation, "Fire and geomorphological processes," by F. J. Swanson. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.*

material, and sometimes actual fusing of the soil surface (Dyrness et al. 1957; Ahlgren and Ahlgren 1960; Brown 1972; Helvey 1972, 1973; Rice 1973; Anderson et al. 1976; Campbell et al. 1977). In general, these factors lead to increases in both soil water-storage and runoff from burned sites.

Contrasts in snow hydrology of burned and unburned ecosystems have received little study, particularly in terms of fire-induced changes in groundwater regime (see footnote 3). Snow accumulation and melt in open (clearcut or naturally treeless) and forested areas have been the subject of extensive research; a stand of blackened snags presents a vastly different environment from either forested or treeless areas. Speculation on snow hydrology of burned areas is complicated by the great contrasts between cold/dry and warm/wet snow types and between snowpack and multiple accumulation/melt seasonal regimes. Work on warm snowpacks by Smith (1974) and others does suggest, however, that formation of melt zones around blackened snags and rapid-condensation melting may add more meltwater to the soil in burned areas than in forests and snag-free open areas. Forests may have greater loss by evaporation; snowpacks in open areas may contain continuous, relatively impermeable horizons that carry meltwater directly to streams.

Destruction of covering vegetation by fire opens the channel to direct sunlight, increasing water temperatures and perhaps producing substantial increases in organic debris loading from falling limbs, litter, and trees. The increase in stormflow and acceleration of erosion depends on the intensity, severity, and frequency of burning and how much of a particular watershed burned (Anderson et al. 1976). If much foliage is destroyed, interception and evapotranspiration are reduced, and the potential for accelerated landslide activity from root deterioration is increased. Where the organic layers of the forest floor are also consumed and mineral soil is exposed, infiltration and soil water-storage capacities are reduced, greatly increasing surface erosion and runoff potential.

Massive wildfires in western forests have accelerated both erosion and sedimentation as a result of these processes. Studies of fire-denuded watersheds in west-central Washington (Klock and Helvey 1976a and b) showed that maximum streamflows were double the rate of flows before the fire. In addition, as the result of combined rapid snowmelt, high intensity rainstorms, and the destruction of covering and anchoring vegetation, massive debris torrents occurred 2 years after the burn with a frequency 10 to 28 times greater than before the fire. Noble and Lundeen (1971) report a postfire erosion rate of 413.3 m^3/km^2 per year for a portion of the South Fork Salmon River in the Idaho Batholith. This amounts to an acceleration seven times greater than sediment yield for similar, but unburned, lands in the vicinity (Megahan and Molitor 1975).

In northern California, Wallis and Anderson (1965) reported sediment discharge 2.3 times greater from burned than from unburned areas Seventeen years after the Tillamook Burn in the Wilson River watershed of Oregon, the annual rate of sediment discharge was 175.3 t/km^2, 5-8 times that of nearby unburned forested watersheds with similar geology (Anderson 1954).

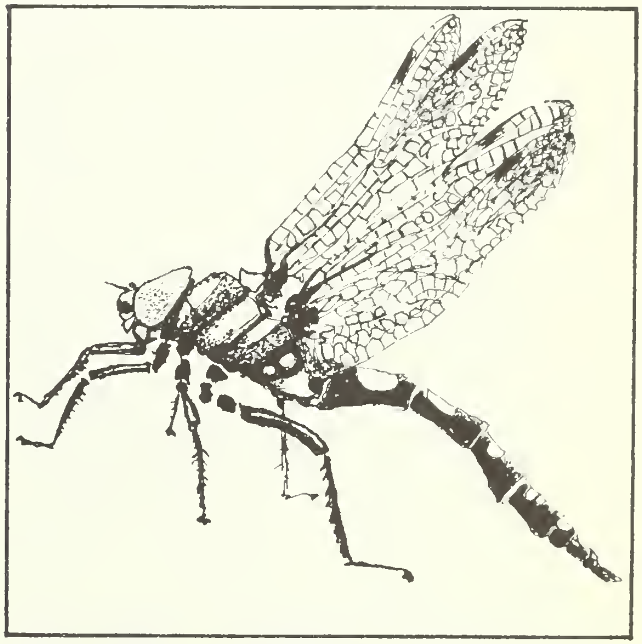
Fire affects nutrient availability and subsequent nutrient loading of streams in several ways. Nutrients incorporated in vegetation, litter, and soil can be volatilized during pyrolysis and combustion, mineralized during oxidation, or lost by ash convection (Grier 1975). After the fire is out, nutrients can then be redistributed by leaching of the ash layer and soil and transported to the stream by surface erosion, soil mass movement, or solution transport. Studies on nutrient transfer to streams after wildfire and controlled fire in the western Cascades of Oregon (R. L. Fredriksen, Forestry Sciences Laboratory, Corvallis, personal communication) and in north-central Washington (Tiedemann 1973, Grier 1975), indicate that after a fire, free nitrogen concentrations were lower than in nonburned areas, nitrate increased, and phosphorus may have increased slightly. In western Oregon, Fredriksen (personal communication) reported that pH changes generally last less than 1 month, increased phosphorus concentrations no more than 2 years, and increased nitrate concentrations from 1 to 10 years.

The impact of these changes in nutrient concentration on salmonid productivity is not well known. The levels of increased nutrients reported in streams after fire appear to be below toxic thresholds for aquatic organisms and dissipate rapidly with stream dilution and flushing.

Gibbons and Salo (1973) pointed out that the addition of nutrients to a stream may be beneficial, especially to relatively sterile streams, by supporting additional plant and animal life; such results remain difficult to predict, however, and excessive nutrient loading may result in eutrophication.

CONCLUSIONS

The natural events described may operate separately or in combination to create limiting habitat characteristics in a particular stream section or system. Human activities in the stream and its parent watershed may profoundly affect these events, their frequency, and magnitude. A firm understanding of the natural processes is thus essential for a clear understanding of the effects of forest and rangeland management on the habitat of anadromous salmonids.



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General Technical
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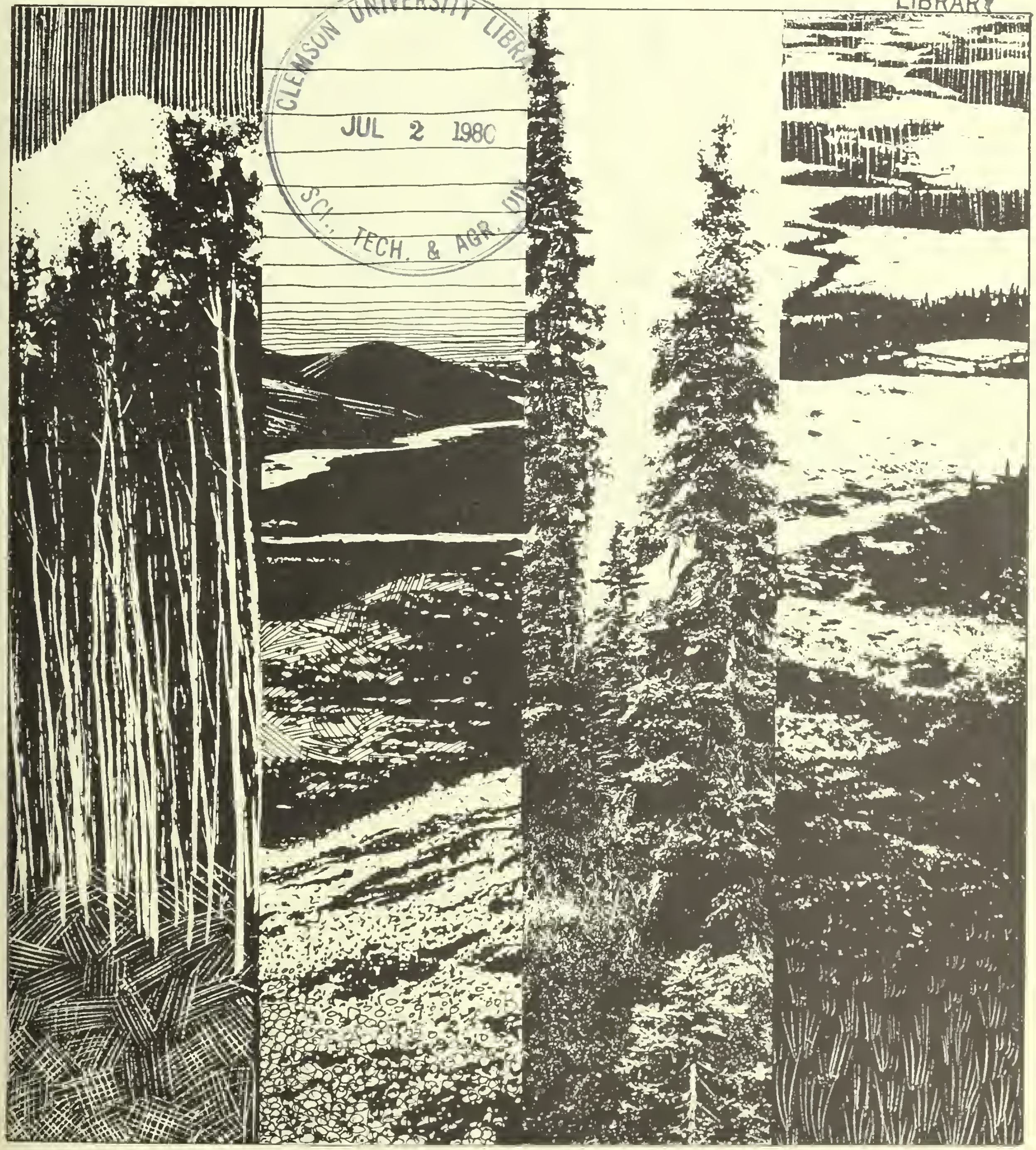
PNW-106

May 1980

A Preliminary Classification System for Vegetation of Alaska

By Leslie A. Viereck and C.T. Dyrness



Abstract

A hierarchical system, with five levels of resolution, is proposed for classifying Alaska vegetation. The system, which is agglomerative, starts with 415 known Alaska plant communities which are listed and referenced. At the broadest level of resolution the system contains five formations — forest, tundra, shrubland, herbaceous vegetation, and aquatic vegetation.

Keywords: Classification (vegetation), communities (plant), Alaska.

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Contents

Preface

The first draft of this classification was produced at the Alaskan Rangeland Workshop in Anchorage in February 1976; it had four levels of resolution. In June 1976 it was revised, and the second draft, with five levels, was sent out for review. The committee that worked on these early drafts included, in addition to the authors, William Gabriel (Bureau of Land Management, Anchorage), Samuel Rieger (Soil Conservation Service, Anchorage), William Mitchell (University of Alaska, Palmer), and David Murray (University of Alaska, Fairbanks).

Many others contributed significantly to the classification. Paul Alaback (Oregon State University, Corvallis) and Bonita Neiland (University of Alaska, Fairbanks) provided information on the coastal southeast Alaska forest types. Allen Batten and David Murray (University of Alaska, Fairbanks) provided a literature review and much of the background information on the tundra types. In addition, Mr. Batten reviewed many of the vegetation descriptions and determined the synonomy of many vegetation types. Peter Scorup (University of Alaska, Palmer), Kenneth Winterberger (USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Anchorage), Paula Krebs (Bureau of Land Management, Anchorage) and Patrick Webber (University of Colorado, Boulder) provided valuable insight on the use of classification in mapping vegetation in tundra and forested areas. Richard Driscoll (USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado) provided very helpful review comments.

We also acknowledge the encouragement to develop this classification by the Federal and State agencies involved in inventory and mapping of vegetation in Alaska.

Introduction

It has become increasingly apparent that a unified statewide system for classifying vegetation in Alaska is needed. Over the years, so many individuals, agencies, and institutions have described and mapped the vegetation that there are many approaches to naming vegetation units currently in use. The lack of uniformity in the approach makes correlation of information between different areas and workers difficult, if not impossible. A generally acceptable hierarchical system that accommodates all major plant groupings in the State is needed. If the levels in the hierarchy are carefully chosen, the classification system should be useful for statewide application as well as for detailed work in localized areas.

This suggested classification will be revised as new information becomes available. Although it reflects input from many biologists, feedback from users will be helpful for later revisions. The goal is a system that can be applied at all levels of resolution and in all areas of the State.

Review of Vegetation Classification Work in Alaska

Interest in vegetation science in Alaska has traditionally been oriented toward the tundra areas. Far more information is available for tundra vegetation than for either taiga or coastal forests. The emphasis is still on tundra, but more effort is now spent on vegetation work in taiga. Following is a brief summary of some available sources of information for use in constructing a statewide vegetation classification system; it will give a general idea of some of the past major vegetation classification efforts in Alaska.

COASTAL FORESTS

Little work has been done in Alaska coastal forests to describe and classify vegetation. A good source of general information on vegetation in southeast Alaska is a report by Palmer (1942) for the Fish and Wildlife Service.[1] Palmer, however, only lists two forest types and six other types for the whole southeastern area. There are detailed descriptions of the vegetation of some coastal areas, such as Coronation and Wornkofski Islands (Klein 1965), Prince William Sound (Cooper 1942), and Glacier Bay. Glacier Bay has also been the subject of numerous studies of plant succession after deglaciation (Cooper 1924, 1939; Lawrence 1958; Crocker and Major 1955). Neiland (1971) described bog vegetation but did not separate distinct vegetation types.

Because of this lack of information, our classification may need considerable additions to accommodate coastal forest communities, especially at the plant community level. Many of the vegetation units in the present system were suggested by scientists currently working in southeast Alaska and are based on work not yet published.

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[1] For the reader's convenience in using this publication, unpublished references are listed with published references in "References."

ALEUTIAN ISLANDS

Amchitka Island has been the focal point for studies of vegetation of the Aleutian Islands. Early work by Hultén (1960) and Tatewaki and Kobayashi (1934), however, gave some general descriptions of Aleutian Island vegetation. Amundsen (1972) described ten plant community types on Amchitka Island; a more detailed description of the vegetation was given by Shacklette et al. (1969) — they listed 15 habitats with 41 plant communities using the system presented by Fosberg (1967).

Our classification system may be incomplete for plant communities of the Aleutian Islands because of the paucity of information for those islands, with the exception of Amchitka Island.

ALPINE TUNDRA

Although considerable information is available on arctic tundra in Alaska, little information is available on alpine plant communities. Palmer (1942) and Viereck (1962a, 1962b, 1963) described plant communities in the Alaska Range; Scott (1972), the Wrangell Mountains; Dean (1964), the Baird and Schwatka Mountains; and Anderson (1972), the Tanana-Yukon upland at Eagle Summit.

Murray and Batten (1977) summarized information on alpine plant communities and incorporated them into a provisional classification. Their plant communities were used as the starting point for our tundra classification.

ARCTIC TUNDRA

It is impossible to review all the considerable work on classification and description of vegetation in the Alaska arctic tundra. Notable studies include those of Spetzman (1959), Britton (1967), Johnson et al. (1966), and Johnson and Tiezen (1973). Both Spetzman (1959) and Britton (1967) made general vegetation descriptions throughout the arctic tundra area north of the crest of the Brooks Range. At Cape Thompson, Johnson et al. (1966) described and mapped 13 types and arranged the types along gradients of moisture, soil texture, and slope.

Johnson and Tiezen (1973) reviewed the vegetation work in arctic Alaska and listed 42 community types in ten physiographic habitats. They did not describe the community types but did correlate eight major types with soil texture, drainage, soil type, and level of permafrost. The 42 community types represent a mix of habitats and general vegetation physiognomy and plant groups.

Hettinger and Janz (1974) described vegetation and soils in northeastern Alaska; they identified and described 67 vegetation types and correlated them with terrain and soil features. Koranda and Evans (1975) classified the vegetation between the foothills of the Brooks Range and the Arctic Ocean, partially on the basis of physiography or topographic feature, but gave little information on species composition. Webber and Walker (1975) described 12 vegetation types which were mapped in the Prudhoe Bay area. Murray and Batten (1977) listed all arctic tundra communities that have been described in the literature; their work is the basis of our proposed classification of Alaska tundra vegetation.

INTERIOR ALASKA FORESTS (TAIGA)

Little information and few quantitative analyses are available for vegetation of the taiga of Alaska. The work accomplished seldom included attempts to classify communities. Two notable exceptions are Hettinger and Janz (1974), who developed a classification for the northeastern corner of the State, and Hanson (1953), who classified taiga communities in northwestern Alaska.

Viereck (1975), after reviewing available information on taiga communities, developed a classification that followed the system developed by Fosberg (1967) for the International Biological Program. Whenever possible, Viereck made his classification compatible with Reid's (1974) for an adjacent area in Canada. Viereck showed relative positions of all vegetation types along hypothetical moisture and temperature gradients. All interior Alaska forest communities in our classification are based on Viereck's (1975) work. Because of our incomplete knowledge of taiga types, many additional communities will undoubtedly be added in the future.

ENTIRE STATE OF ALASKA

All statewide vegetation classifications we know of were developed for use with large-scale vegetation maps. Spetzman's (1963) map, at a scale of 1:2,500,000, is the basis of subsequent vegetation maps of Alaska. Map units shown are four forest types (coastal western hemlock-Sitka spruce, bottomland spruce-poplar, upland spruce-hardwood, and lowland spruce-hardwood); three tundra types (moist, wet, and alpine); two shrub types (high brush and low brush); and muskeg-bog. A slightly modified version of this map was published at the same scale in 1973 by the Joint Federal-State Land Use Planning Commission for Alaska.

The National Atlas of the USA contained a map of the potential vegetation of Alaska constructed by Küchler (1969) at a scale of 1:7,500,000. The vegetation units are similar to Spetzman's (1963), although many names were changed. In the taiga, Küchler combined the upland units into one unit termed spruce-birch forests; the low mixed type he renamed black spruce forest; and the wet, moist, and alpine tundra of Spetzman he renamed water sedge tundra, cotton sedge tundra, and dryas meadows and barrens, respectively. Küchler also recognized that vegetation of the Aleutian Islands differs from that of northern and western Alaska by identifying two distinct types: Aleutian meadows and Aleutian heath and barrens.

Viereck and Little (1972) published a map of the vegetation of Alaska, only slightly modified from Spetzman's map. They provided an extensive description of the mapped units, as well as a further division and description of additional vegetation units.

Proposed Classification System

In keeping with recent national trends, we have devised a "pure" classification system, that is, it is based, as much as possible, on the characteristics of the vegetation itself. Although many systems have combined vegetation, soils, landform, and climate, a single component classification has distinct advantages. Because only vegetation is classified, a logical, consistent hierarchical system can be developed. In the ideal hierarchical system, each unit is exclusive of all others, and when one class at any level is known, all levels above it are automatically known. Such a system should be as objective as possible. Boundaries of the types should be fixed and spelled out so that marginal situations can be consistently categorized by all users. Actually, it is virtually impossible to be entirely objective in determining classes and class boundaries, but objectivity should be the aim.

By restricting our classification to vegetation, we do not imply that information on other portions of the ecosystem (for example, soils and landforms) is not important; in many applications this information is as important as knowledge of the vegetation. By keeping the classification pure, we attempt to provide the greatest flexibility and a more universal applicability. As Davis and Henderson (1976) stated, "an integrated system predetermines the way components are combined, makes a value judgment about which are important and which are not, and thus limits its application to only those situations it was specifically designed for."

In local areas, many land managers will prefer at least a partially integrated system. A manager might, for example, refer to "wet sedge-grass tundra on alluvial fans." A generally accepted hierarchical classification for soils exists, and one for landforms could easily be devised. It should be stressed, however, that combinations of units from various classifications would change from place to place, as would their significance for management limitations. Hence, a combined approach, using elements from different classifications, should be for strictly local application.

Bailey et al. (1978) summarized the types and characteristics of resource classification systems. They noted that the most basic system is a taxonomic classification that is independent of place. For maximum usefulness, a classification should be based on many characteristics. Our classification is based on all the plants at any location — the relative abundance of individual plant species. It is well to keep in mind that our proposed system is a taxonomic classification designed to serve many needs. In this respect, it is a natural rather than an artificial classification designed to meet a narrowly defined need (Bailey et al. 1978).

Our classification has been developed by aggregation, with plant communities as the basic elements. We started with known communities, grouping them into broader classes based on similarity of composition by species. Some plant communities we have listed have been described in great detail, others in only a sketchy manner. In all cases, however, we attempted to list at least one reference for each community. Generally, the communities are named for dominant species in principal layers (tree, tall shrub, low shrub, herb). In some cases, however, species with high indicator value are also listed.

This system is designed to classify existing vegetation, not potential vegetation. A classification for potential vegetation must be built on a solid background of knowledge of successional relationships of all vegetation types. Since the successional status of many plant communities in Alaska is, as yet, unknown, we concentrated on existing vegetation. The successional relationships of the vegetation units are important and will be included in future detailed descriptions when information is available.

The proposed system has four formations for terrestrial vegetation — forest, tundra, shrubland, and herbaceous vegetation — and one formation for aquatic vegetation; these formations constitute level I. At the finest level of resolution (level V) units are discrete plant communities, with levels II, III, and IV intermediate in resolution. The scope of the system is shown by the number of units: level II contains 15 units; level III, 39; level IV, 126; and level V, 415.

FOREST

The level II classes for forest are conifer, deciduous, and mixed. A conifer forest is one in which over 75-percent of total tree cover is contributed by coniferous species. Similarly, a deciduous forest has over 75-percent of the tree cover in deciduous tree species. In a mixed stand, neither conifers nor deciduous species have clear dominance; both contribute 25 to 75 percent of the total canopy cover.

The classes in level III are based on amounts of tree canopy cover and are those suggested by Fosberg (1967) — closed, open, and woodland. Closed stands have from 60- to 100-percent crown canopy. Crown cover is best determined from aerial photographs. Open stands have from 25- to 60-percent crown canopy cover. Woodland has only scattered trees and a canopy cover of 10 to 25 percent. Areas with less than 10-percent tree cover are not classed as forest.

TUNDRA

The level II classes for tundra are sedge-grass tundra, herbaceous tundra, tussock tundra, shrub tundra, and mat and cushion tundra. These are generally recognized classes, and many of these terms are already in use. By herbaceous we mean nongrasslike, nonwoody plants — sometimes referred to as forbs. We have narrowed the classification under tundra by listing many grass types as herbaceous vegetation and many of the shrub types as shrubland.

We assigned grass meadows, except those in the arctic, to the herbaceous vegetation formation. Under this approach, all grass communities in the Aleutian Islands and Kodiak Island and in south-central Alaska are classified as grassland rather than tundra. Common grass species, such as *Calamagrostis canadensis* and *Elymus arenarius,* are restricted to the herbaceous vegetation formation. Grasses in sedge-grass tundra are, on the other hand, mostly typical arctic species; e.g., *Arctagrostis latifolia* and *Poa arctica.*

The separation between shrubland and shrub tundra is more difficult to define. Although the ericaceous shrubs (e.g., *Empetrum nigrum* and *Vaccinium uliginosum*) are mainly confined to shrub tundra, other shrub species (such as *Salix planifolia*) are conspicuous elements in both shrubland and shrub tundra. Until more data are gathered, the separation cannot be made simply on the basis of floristics. The classification at present should be partially based on location; for example, stands of ericaceous shrubs and low willows north of the Brooks Range are best classified as shrub tundra, whereas an equivalent vegetation type in lowlands south of the Brooks Range are classified as shrubland. Stands classed as shrub tundra, however, would include sizable amounts of typically tundra sedges, herbs, and mosses — species not occurring in shrubland stands.

Mat and cushion tundra is differentiated from shrub tundra mostly on the basis of height. Mat and cushion is made up of prostrate shrubs (most commonly dryas) which rarely surpass 20 centimeters (about 8 inches) in height. Closed mat and cushion stands have more than 75-percent cover in prostrate shrubs and other species. Open mat and cushion occurs on less productive sites and generally has only 50- to 75-percent plant cover.

SHRUBLAND

Most shrubland communities are dominated by willow, alder, or birch; therefore, level III and IV classes are mainly based on these genera. Tall shrubs are generally over 1.5 meters (about 5 feet) in height; low shrubs, less than 1.5 meters. Under level IV, closed shrub stands have a shrub canopy cover greater than 75 percent, whereas canopy cover in open shrub stands ranges from 25 to 75 percent.

HERBACEOUS VEGETATION

The major classes of herbaceous vegetation at level II are tall grass, midgrass, and sedge-grass. Tall grass, as defined by Fosberg (1967), is made up of graminoid plants which are over 1 meter (3.3 feet) tall when fully developed. For our purposes, midgrass includes all grass stands with a maximum height of less than 1 meter.

The major grass species in tall grass communities are *Calamagrostis canadensis* and *Elymus arenarius*. *Calamagrostis canadensis* on dry sites is also included under midgrass because of its shorter stature in these less productive areas. Another midgrass species characteristic of dry sites is *Festuca altaica*.

The herbaceous sedge-grass includes both freshwater and saline marshes where woody plants are virtually absent. The freshwater marshes that include a substantial component of shrubs are classified as shrubland.

AQUATIC VEGETATION

This category covers all plant life in permanent bodies of water, whether they be streams, lakes, or ocean. This category has not been developed in the present classification, and much work remains to be done.

DOCUMENTED PLANT COMMUNITIES (LEVEL V)

Under level V we list the plant communities and references known to us. We have standardized the community names by listing only the most significant species. Species in community names separated by hyphens are in the same layer; a slash between species indicates a change in layer (tree layer to shrub, shrub to herb layer, etc.). Some references listed for the communities give complete descriptions; others mention only the community name.

In many cases, elements of higher levels can easily be combined with community names for greater clarity. For example, a *Picea mariana/Sphagnum-Cladonia* community is listed under both open black spruce and black spruce woodland. In actual practice, these communities should be referred to as open *Picea mariana/Sphagnum-Cladonia* and woodland *Picea mariana/ Sphagnum-Cladonia,* respectively. This not only differentiates between the two communities but also provides more information in the community name.

The provisional classification follows. Nomenclature is standardized to Hultén (1968) for herbaceous vascular plants, Viereck and Little (1972) for woody plants, Crum et al. (1973) for mosses, Hale and Culberson (1970) for lichens, and Worley (1970) for hepatics.

Preliminary Classification for Alaska Vegetation

Level I	Level II	Level III	Level IV	Level V
1. Forest	A. Conifer forest	(1) Closed conifer forest	a. Sitka spruce — occupies wet sites in southeastern Alaska, primarily alluvial flood plains; occurs as a narrow coastal band in south-central Alaska and occupies much of the forested area on Afognak Island.	*Picea sitchensis/Oplopanax horridum-Rubus spectabilis/Cornus canadensis* (Alaback 1980, Neiland 1971, Stephens et al. 1969)
			b. Sitka spruce-western hemlock — occurs on moist sites throughout southeastern Alaska and in a narrow coastal band in south-central Alaska.	*Picea sitchensis-Tsuga heterophylla/Lysichiton americanum/Sphagnum* spp. (Alaback 1980, Neiland 1971, Stephens et al. 1969) *Picea sitchensis-Tsuga heterophylla/Vaccinium ovalifolium-V. alaskensis-Menziesia ferruginea* (Neiland 1971, Stephens et al. 1969) *Picea sitchensis-Tsuga heterophylla/Moneses uniflora-Tiarella trifoliata/Mnium* spp. (Neiland 1971, Stephens et al. 1969)
			c. Western hemlock-Sitka spruce-(western redcedar) — is a widespread forest type in southeastern Alaska. It also occurs in a narrow coastal band in south-central Alaska. South of 57°N, it usually contains western redcedar.	*Tsuga heterophylla-Picea sitchensis-(Thuja plicata)/Vaccinium ovalifolium-V. alaskensis/Rhytidiadelphus loreus* (Alaback 1980, Neiland 1971, Stephens et al. 1969) *Tsuga heterophylla-Picea sitchensis-(Thuja plicata)/Lysichiton americanum/Sphagnum recurvum* (Neiland 1971)
			d. Western hemlock-western redcedar — occurs in low producing, poorly drained ecosystems in southeastern Alaska.	*Tsuga heterophylla-Thuja plicata/Vaccinium ovalifolium-Lysichiton americanum* (Alaback 1980, Stephens et al. 1969)
			e. Mountain hemlock — occurs near timberline, normally on saturated soils. This type covers considerable land area both on the mainland and on the major islands of southeastern Alaska. It also occurs as a narrow subalpine band in south-central Alaska.	*Tsuga mertensiana/Vaccinium ovalifolium Cladothamnus pyrolaeflorus* (Alaback 1980, Stephens et al. 1969)
			f. Western hemlock-mountain hemlock — in southeastern Alaska, is transitional between the subalpine mountain hemlock zone and the Sitka spruce-western hemlock zone.	*Tsuga heterophylla-T. mertensiana/Vaccinium ovalifolium-V. alaskensis/Rubus pedatus/Rhytidiadelphus loreus* (Neiland 1971)
			g. Silver fir — has a limited distribution in southern portions of southeastern Alaska.	*Abies amabilis-Tsuga heterophylla* (Juday et al. 1979)
			h. Subalpine fir — occurs in scattered locations near treeline in southeastern Alaska.	*Abies lasiocarpa-Tsuga mertensiana* (Harris 1965, Worley and Jaques 1973)
			i. Black spruce — generally occurs on poorly drained organic soils, often underlain by permafrost. It has wide distribution in interior, western, southwestern, northwestern, and south-central Alaska.	*Picea mariana*/feathermoss (Drury 1956, Lutz 1956, Neiland and Viereck 1977, Viereck 1975) *Picea mariana/Rosa acicularis/Peltigera* (Foote 1976, LaRoi 1967)
			j. Black spruce-white spruce — occurs in interior Alaska near the northern and western limits of trees. It also occurs on terraces and at the base of south-facing slopes.	*Picea mariana-P. glauca*/feathermoss (Foote 1976; LaRoi 1967, Neiland and Viereck 1977; Viereck 1970a, 1975)

	k. White spruce — is widespread in south-central and interior Alaska and extends to the limits of tree growth along rivers draining the Brooks Range. It generally occupies sites with well-drained, permafrost-free soils.	*Picea glauca*/feathermoss (Buckley and Libby 1957; Drury 1956; Viereck 1970a, 1975) *Picea glauca/Viburnum edule/Equisetum arvense* (Foote 1976) *Picea glauca/Linnaea borealis-Equisetum sylvaticum* (Foote 1976)
(2) Open conifer forest	a. Shore pine-western hemlock-(western redcedar-Alaska yellow-cedar) (western redcedar south of 57° N) — is limited in southeastern Alaska and generally found on boggy, poorly drained sites that are locally termed muskegs and bogs.	*Pinus contorta-Tsuga heterophylla-(Thuja plicata-Chamaecyparis nootkatensis)/Vaccinium ovalifolium V. alaskensis-Ledum groenlandicum/Sphagnum squarrosum* (Neiland 1971)
	b. Sitka spruce — occurs in coastal areas in south-central and southeastern Alaska, often on alluvial deposits and glacial moraines and outwash, and adjacent to coastal wetlands.	*Picea sitchensis/Alnus sinuata/Calamagrostis canadensis* (Viereck 1979, Worley 1977) *Picea sitchensis/Alnus tenuifolia*
	c. Mountain hemlock — forms a transition between the continuous closed stands of mountain hemlock and the alpine tundra zone in southeastern Alaska.	*Tsuga mertensiana/Cassiope* spp.-*Vaccinium ovalifolium-Fauria crista-galli* (Alaback 1980, Jaques 1973)
	d. Black spruce-white spruce — occurs mostly near treeline in interior, southwestern, western, northwestern, and south-central Alaska.	*Picea mariana-P. glauca/Betula glandulosa* (Viereck 1979)
	e. White spruce — is similar to the closed white spruce type but with more shrub cover because of the more open tree canopy. Found commonly on well-drained sites and near treeline in interior, southwest, northwest, and south-central Alaska.	*Picea glauca/Betula glandulosa/Hylocomium splendens* (Hettinger and Janz 1974; Viereck 1970b, 1975, 1979, Williamson and Peyton 1962) *Picea glauca/Betula glandulosa/Sphagnum* (Hettinger and Janz 1974; Viereck 1970b, 1975, 1979; Williamson and Peyton 1962) *Picea glauca/Betula glandulosa/Cladonia* (Racine and Anderson 1979, Viereck 1979) *Picea glauca/Alnus tenuifolia*
	f. Black spruce — is extremely common on poorly drained, cold sites in interior and south-central Alaska.	*Picea mariana/Vaccinium*/feathermoss (Drury 1956; Foote 1976; Lutz 1956; Viereck 1975, 1979) *Picea mariana*/feathermoss-*Cladonia* (Foote 1976; Viereck 1975, 1979) *Picea mariana/Sphagnum-Cladonia* (Neiland and Viereck 1977)
	g. Black spruce-tamarack — is found on wet lowland sites with shallow permafrost. It is restricted to interior Alaska.	*Picea mariana-Larix laricina*

Preliminary Classification for Alaska Vegetation (Continued)

Level I	Level II	Level III	Level IV	Level V
1. Forest (continued)	A. Conifer forest (continued)	(3) Conifer woodland	a. Shore pine-(Alaska yellow-cedar) – is found only in southeastern Alaska and is generally on boggy, poorly drained sites.	*Pinus contorta-(Chamaecyparis nootkatensis)/Empetrum nigrum-Ledum groenlandicum/Carex pluriflora/Sphagnum fuscum* (Neiland 1971) *Pinus contorta-(Chamaecyparis nootkatensis)/Vaccinium uliginosum/Trichophorum cespitosum/Sphagnum compactum-S. tenellum*-lichens (Neiland 1971) *Pinus contorta-(Chamaecyparis nootkatensis)/Carex livida-Eriophorum angustifolium/Sphagnum lindbergii-S. papillosum* (Neiland 1971) *Pinus contorta-(Chamaecyparis nootkatensis)/Drosera anglica-Rhynchospora alba/Sphagnum lindbergii-S. tenellum* (Neiland 1971) *Pinus contorta/Kalmia polifolia/Eriophorum angustifolium-Carex pluriflora-Tofieldia occidentalis-Fauria crista-galli/Sphagnum lindbergii-S. compactum* (Neiland 1971) *Pinus contorta/Carex livida-C. phyllomanica-Rubus arcticus-Platanthera dilitata/Sphagnum papillosum-S. recurvum* (Neiland 1971)
			b. Black spruce – is found on wet, boggy sites where it often grades into a sphagnum bog, and on dry upland sites where lichens are frequently important in the understory. It is common in interior, south-central, southwest, and northwest Alaska.	*Picea mariana/Vaccinium-Salix* (Racine 1976) *Picea mariana/Sphagnum-Cladonia* (Viereck 1975, 1979) *Picea mariana/Cladonia* (Foote 1976; Racine 1976; Viereck 1975, 1979)
			c. Black spruce-white spruce – occurs in interior, south-central, southwest, and northwest Alaska, especially near the northern, western, and altitudinal limit of trees.	*Picea mariana-P. glauca/Betula glandulosa*/feathermoss (Viereck 1979) *Picea glauca-P. mariana*/lichen (Foote 1976)
			d. White spruce – is a very open, woodland type especially common at the northern limits of tree growth and at elevational tree lines.	*Picea glauca/Betula glandulosa*/feathermoss-*Cladonia* (Hettinger and Janz 1974; Racine 1975; Viereck 1975, 1979; Williamson and Peyton 1962) *Picea glauca/Dryas*-moss (Viereck 1979) *Picea glauca/Cladonia* (Racine 1976) *Picea glauca/Salix lanata/Cladonia* (LaPerriere 1979)
	B. Deciduous forest	(1) Closed deciduous forest	a. Red alder – occupies moist sites and disturbed areas in southeastern Alaska.	*Alnus rubra* (del Moral and Watson 1978)
			b. Black cottonwood – is generally found along streams in southeastern and south-central Alaska.	*Populus trichocarpa*
			c. Balsam poplar – occurs most frequently on river flood plains in interior, south-central, and southwestern Alaska, although there are several isolated clumps on the north slope of the Brooks Range.	*Populus balsamifera/Alnus tenuifolia/Calamagrostis canadensis* (Buckley and Libby 1957; Drury 1956; Hettinger and Janz 1974; Lutz 1956; Neiland and Viereck 1977; Racine 1976; Viereck 1970a, 1975) *Populus balsamifera/Salix barclayi/Heracleum lanatum* (Viereck 1970b) *Populus balsamifera/Salix-Alnus*/herb (Viereck 1979)

		d. Paper birch — occurs on a variety of upland sites, both with and without permafrost, in interior and south-central Alaska.	*Betula papyrifera/Alnus crispa/Calamagrostis* (Buckley and Libby 1957; Lutz 1956; Viereck 1975) *Betula papyrifera/Viburnum* (Foote 1976) *Betula papyrifera/Alnus-Salix* (Racine 1976)
		e. Aspen — occurs on warm, well-drained upland soils in interior and south-central Alaska.	*Populus tremuloides/Viburnum edule/Linnaea borealis* (Foote 1976) *Populus tremuloides/Salix* spp./*Arctostaphylos uva-ursi* (Hettinger and Janz 1974; Viereck 1975)
		f. Birch-aspen — is found on moderately warm sites in interior and south-central Alaska and is generally replaced by white spruce.	*Betula papyrifera-Populus tremuloides*
	(2) Open deciduous forest	a. Paper birch — occurs on dry to moist sites in interior, south-central, and western Alaska. On drier sites, lichens are important in the understory; on moist sites, shrubs are dominant.	*Betula papyrifera/Cladonia* (Racine 1976) *Betula papyrifera/Betula glandulosa/Hylocomium* (Hanson 1953; Hettinger and Janz 1974; Viereck 1975, 1979) *Betula papyrifera/Viburnum edule/Calamagrostis* (Foote 1976)
		b. Aspen — occurs primarily on extremely dry sites on steep south slopes in interior and south-central Alaska.	*Populus tremuloides/Arctostaphylos uva-ursi*
		c. Balsam poplar — occurs as open clumps near tree line in interior, south-central, southwestern, and northwestern Alaska and as isolated groves on the north slope of the Brooks Range.	*Populus balsamifera/Salix-Alnus/Calamagrostis* (Racine and Anderson 1979; Viereck 1979)
	(3) Deciduous woodland	a. Paper birch — occurs on dry sites, such as old sand dunes and coarse gravel deposits, in northwest Alaska and the northern portion of interior Alaska.	*Betula papyrifera/Cladonia* (Racine 1976)
C. Mixed conifer and deciduous forest	(1) Closed mixed forest	a. Spruce-birch — tends to occur on cool, wet sites when black spruce is present in the mixture; white spruce favors warmer, drier sites. The type is found primarily in interior and south-central Alaska and, to a lesser extent, in northwest and southwest Alaska.	*Picea glauca-Betula papyrifera/Alnus crispa/Calamagrostis canadensis* (Buckley and Libby 1957; Hettinger and Janz 1974; Lutz 1956; Viereck 1975) *Picea mariana-Betula papyrifera/Ledum* *Betula papyrifera-Picea glauca-P. mariana/Calamagrostis* (Foote 1976)
		b. Aspen-spruce — is an intermediate successional stage, with spruce as the eventual climax. Aspen generally occurs with white spruce on warm, well-drained sites. The type is most common in interior and south-central Alaska.	*Populus tremuloides-Picea glauca/Arctostaphylos uva-ursi* (Buckley and Libby 1957; Lutz 1956; Viereck 1975) *Populus tremuloides-Picea mariana/Ledum* (Viereck 1975) *Populus tremuloides-Picea mariana/Cornus canadensis* (Foote 1976)
		c. Poplar-spruce — is an intermediate successional stage leading to white spruce climax on flood plain sites in interior, south-central, southwestern, and northwestern Alaska.	*Populus balsamifera-Picea glauca/Alnus/Equisetum*

Preliminary Classification for Alaska Vegetation (Continued)

Level I	Level II	Level III	Level IV	Level V
1. Forest (continued)	C. Mixed conifer and deciduous forest (continued)	(2) Open mixed forest	a. Spruce-birch — occurs on a variety of upland sites in interior, south-central, southwestern, and northwestern Alaska.	*Picea glauca-Betula papyrifera/Calamagrostis-Hylocomium* (Hettinger and Janz 1974; Viereck 1975) *Picea glauca-Betula papyrifera/Alnus crispa/Sphagnum* (Viereck 1975) *Picea glauca-Betula papyrifera/Salix planifolia/Sphagnum* (Viereck 1970b) *Picea mariana-Betula papyrifera/Cladonia*
2. Tundra	A. Sedge-grass tundra	(1) Wet sedge-grass	a. Wet sedge meadow — is found in very wet areas, generally underlain by permafrost, in every part of the State except southeast but is especially characteristic of the arctic coastal plain.	*Carex aquatilis* (Churchill 1955; Clebsch 1957; Fries 1977; George et al. 1977; Komárková and Webber 1978, 1980; Scott 1974; Spetzman 1959; Webber 1978; Webber et al. 1978; White et al. 1975; Young 1971) *Carex aquatilis-Eriophorum angustifolium* (Batten 1977; Childs 1969; Hopkins and Sigafoos 1951; Johnson et al. 1966; Kessel and Schaller 1960; Pegau 1968; Racine 1977; Racine and Young 1978; Webber and Walker 1975; Webber et al 1978; Young 1974; Young and Racine 1978) *Carex aquatilis-C. rotundata* (George et al. 1977; Hanson 1953; Pegau and Hemming 1972) *Carex aquatilis-C. chordorrhiza-C. limosa-C. microglochin-Eriophorum scheuchzeri-E. angustifolium* (Drew and Shanks 1965) *Eriophorum angustifolium* (White et al. 1975) *Eriophorum angustifolium-Carex chordorrhiza* (Webber et al. 1978) *Eriophorum angustifolium-Carex aquatilis-C. lachenalii* (Klein 1958; Rausch and Rausch 1968) *Eriophorum angustifolium-Carex bigelowii* (Anderson 1974; Hanson 1950; Koranda 1960; Viereck 1963) *Carex bigelowii-C. rariflora-C. saxatilis* (Hettinger and Janz 1974) *Carex chordorrhiza* (Batten 1977; Spetzman 1959) *Carex rariflora* (Batten 1977; Hanson 1951; Spetzman 1959)
			b. Wet sedge-grass meadow — is largely confined to the arctic coastal plain in very wet areas underlain by shallow permafrost.	*Carex aquatilis-Dupontia fischeri* (Potter 1972; Webber and Walker 1975; Webber et al. 1978; White et al. 1975; Wiggins 1951) *Dupontia fischeri-Eriophorum angustifolium* (Dennis 1969, Webber 1978) *Dupontia fischeri-Eriophorum scheuchzeri* (Spetzman 1959) *Dupontia fischeri-Carex aquatilis-Eriophorum scheuchzeri-E. angustifolium* (Clebsch 1957; Dennis 1969; Potter 1972; Wiggins 1951) *Eriophorum angustifolium-Carex glareosa-Deschampsia caespitosa-Dupontia fischeri-Arctagrostis latifolia* (Johnson et al. 1966)

	... is usually of minor extent, such as on streamsides and pond margins.	*Carex aquatilis-Potentilla palustris* (Bliss and Cantlon 1957; Webber et al. 1978) *Carex aquatilis-Menyanthes trifoliata* (Webber et al. 1978) *Carex aquatilis-C. membranacea-Petasites frigidus* (Scott 1974) *Carex nigricans-Eriophorum angustifolium-Fauria crista-galli-Trichophorum caespitosum* (Jaques 1973)
(2) Mesic sedge-grass	a. Mesic sedge-grass meadow – is usually of minor extent.	*Carex aquatilis-Poa arctica* (Clebsch 1957; Webber 1978) *Carex microchaeta-Poa arctica* (Batten 1977) *Carex podocarpa-Arctagrostis latifolia* (Scott 1974)
	b. Mesic sedge-herb meadow – is usually of minor extent; probably most common in south-central and southeastern Alaska	*Carex macrochaeta-Geranium erianthum-Erigeron peregrinus-Lupinus nootkatensis* (Hjeljord 1971)
	c. Arctic grass-herb meadow – occurs in small, limited areas, mainly reported from the arctic slope but probably more widespread.	*Epilobium latifolium-Mertensia paniculata-Arctagrostis latifolia* (Anderson 1974) *Bromus pumpellianus-Trisetum spicatum-Bupleurum triradiatum* (Koranda 1960) *Luzula confusa-Poa arctica-Petasites frigidus* (Wiggins 1951)
(3) Sedge-shrub	a. Sedge-willow – is widely distributed in tundra areas throughout Alaska, except the south-central and south-eastern parts; probably most abundant from the Brooks Range northward.	*Carex aquatilis-Salix planifolia* (Childs 1969; Clebsch 1957, Dennis 1969; Hanson 1951; Hettinger and Janz 1974; Webber et al. 1978) *Carex aquatilis-Salix lanata* (Scott 1974; Spetzman 1959) *Carex aquatilis-Alnus crispa-Salix* spp. (Bliss and Cantlon 1957) *Carex bigelowii-Salix planifolia* (Hettinger and Janz 1974; Johnson et al. 1966; Koranda 1960) *Carex bigelowii-Salix reticulata-S. planifolia* (Batten 1977; Hettinger and Janz 1974) *Carex bigelowii-Salix reticulata* (Hettinger and Janz 1974) *Eriophorum angustifolium-Salix planifolia* (Fries 1977) *Carex bigelowii-C. membranacea-Salix polaris-Equisetum arvense* (Hanson 1950) *Carex nesophila-Salix rotundifolia-S. reticulata* (Klein 1958) *Carex microchaeta-Salix planifolia-S. reticulata* (Batten 1977)
	b. Sedge-birch – occurs in northern and western interior Alaska.	*Carex bigelowii-Betula nana* (Webber et al. 1978) *Carex bigelowii-C. aquatilis-Betula nana* (Hettinger and Janz 1974)
(4) Sedge-mat and cushion	a. Sedge-dryas – is widely distributed in tundra areas throughout the State, with the exception of south-central and southeastern Alaska.	*Carex aquatilis-Dryas integrifolia* (Webber and Walker 1975; Webber et al. 1978) *Carex bigelowii-Dryas integrifolia* (Childs 1969; Hettinger and Janz 1974; Webber et al. 1978) *Carex bigelowii-Dryas octopetala-Salix reticulata* (Anderson 1974; Scott 1974; Webber et al. 1978) *Kobresia simpliciuscula-Dryas integrifolia* (Webber et al. 1978)
	b. Sedge-bearberry – is only reported from the Seward Peninsula and northeastern interior Alaska but is probably present in other areas, such as the Alaska Range.	*Carex membranacea-Arctostaphylos rubra* (Hettinger and Janz 1974) *Carex bigelowii-Arctostaphylos alpina-Loiseleuria procumbens-Diapensia lapponica* (Racine and Anderson 1979)

Preliminary Classification for Alaska Vegetation (Continued)

Level I	Level II	Level III	Level IV	Level V
2. Tundra (continued)	B. Herbaceous tundra	(1) Low elevation herbaceous tundra	a. Seral herbs — are especially common north of the Brooks Range but are encountered in small areas throughout most of the State.	*Epilobium latifolium* (Scott 1974; Webber et al. 1978) *Epilobium latifolium-Artemisia tilesii* (Batten 1977; Bliss and Cantlon 1957; Johnson et al. 1966; Spetzman 1959) *Epilobium latifolium-Crepis nana* (Young 1974) *Hedysarum alpinum-Artemisia arctica* (Webber et al. 1978) *Cochlearia officinalis-Oxyria digyna-Saxifraga rivularis* (Potter 1972) *Cochlearia officinalis-Phippsia algida-Stellaria humifusa* (Webber 1978) *Wilhelmsia physodes-Artemisia arctica-Chrysanthemum arcticum* (Thomas 1951) *Equisetum variegatum* (Young 1974)
		(2) Alpine herbaceous tundra	a. Herb-sedge (snowbed) — includes a wide variety of types in mountainous areas throughout the State.	*Cetraria delisei-Oxyria digyna-Koenigia islandica-Saxifraga rivularis* (Johnson et al. 1966) *Carex lachenalii-Oxyria digyna-Claytonia sarmentosa* (Scott 1974) *Rhacomitrium canescens-Dicranoweisia cirrata-Oxyria digyna* (Scott 1974) *Anthelia julacea-Scapania paludosa-Saxifraga hirculus-Leptarrhena pyrolifolia* (Shacklette et al. 1969) *Rubus arcticus-Sedum rosea-Polygonum bistorta-Saxifraga hirculus* (Racine and Young 1978) *Carex nigricans* (Jaques 1973)
			b. Alpine herbs — occur primarily as sparse vegetation on talus and blockfields, and in some well-vegetated herbaceous meadows in alpine valleys.	*Saxifraga tricuspidata-Draba caesia* (Batten 1977; Johnson et al. 1966) *Saxifraga oppositifolia* (Griggs 1936) *Saxifraga oppositifolia-Epilobium latifolium* (Viereck 1963) *Saxifraga tricuspidata-Artemisia arctica* (Webber et al. 1978) *Potentilla hyparctica-Cerastium aleuticum-Draba aleutica* (Shacklette et al. 1969) *Artemisia arctica-Potentilla hyparctica-Hierochloe alpina* (Heusser 1954, 1960) *Diapensia lapponica-Saxifraga bronchialis-Sibbaldia procumbens-Trisetum spicatum* (Griggs 1936) *Saxifraga* spp.-*Festuca brachyphylla-Poa glauca-Luzula confusa-Minuartia* spp. (Spetzman 1959) *Oxyria digyna-Saxifraga punctata-Sedum rosea-Primula tschuktschorum* (Fries 1977) *Luetkea pectinata-Cassiope stelleriana-Cladonia* spp.-*Lycopodium alpinum* (Hanson 1951) *Fauria crista-galli-Caltha biflora* (Klein 1965) *Achillea borealis-Arnica unalaschcensis-Claytonia sibirica-Geum calthifolium* (Shacklette et al. 1969) *Polygonum viviparum-Campanula lasiocarpa-Primula cuneifolia-Cardamine umbellata* (Bank 1951)

tundra	(1) Sedge tussock	a. Eriophorum tussock — nearly pure eriophorum tussock vegetation with no important associated species is relatively rare but has been reported from a few localities on the arctic slope	*Eriophorum vaginatum* (Johnson et al. 1966, Komárková and Webber 1978)
	(2) Sedge tussock-shrub	a. Sedge tussock-willow — is mostly restricted to north of the Brooks Range on poorly drained level to gently sloping surfaces.	*Eriophorum vaginatum-Salix planifolia-Carex bigelowii/Hylocomium splendens* (Hettinger and Janz 1974) *Eriophorum vaginatum-Salix planifolia-S. lanata* (Koranda 1960)
		b. Sedge tussock-ericaceous shrub — is scattered in northern and western interior Alaska.	*Eriophorum vaginatum-Carex bigelowii-Ledum palustre-Vaccinium vitis-idaea* (Childs 1969; Dean and Chesemore 1974; Hanson 1950)
		c. Sedge tussock-mixed shrub — is widely distributed throughout the Seward Peninsula and interior and northern Alaska.	*Eriophorum vaginatum-Betula nana-Ledum palustre-Vaccinium* spp. (Clebsch 1957; Drew and Shanks 1965; Hanson 1953; Pegau 1968; Ugolini and Walters 1974; Young and Racine 1978) *Eriophorum vaginatum-Betula nana-Salix planifolia-Ledum palustre-Vaccinium* spp. (Johnson et al. 1966; Koranda 1960; Young 1974) *Eriophorum vaginatum-Betula nana-Salix lanata-Ledum palustre-Vaccinium* spp. (Webber et al. 1978) *Eriophorum vaginatum-Betula nana-Ledum palustre-Vaccinium* spp.-*Carex bigelowii* (Churchill 1955; Hopkins and Sigafoos 1951; Racine 1977; Viereck 1966; Young and Racine 1977) *Eriophorum vaginatum-Betula nana-Salix planifolia-Ledum palustre-Vaccinium* spp.-*Carex bigelowii* (Spetzman 1959; Webber et al. 1978) *Eriophorum vaginatum-Betula nana* (Batten 1977; Kessel and Schaller 1960; Komárková and Webber 1980; Webber et al. 1978) *Carex bigelowii-Betula nana-Salix planifolia-Ledum palustre-Vaccinium* spp. (Racine and Anderson 1979; Racine and Young 1978)
D. Shrub tundra	(1) Willow	a. Willow-sedge — is largely concentrated north of the Brooks Range, where it occurs in the foothills and the arctic coastal plain	*Salix planifolia-Carex aquatilis* (Komárková and Webber 1978, 1980) *Salix lanata-Carex aquatilis* (Webber and Walker 1975; Webber et al. 1978) *Salix lanata-Carex vaginata/Hylocomium splendens* (Hettinger and Janz 1974)
		b. Willow-grass — may not be a very widespread type; it has only been described from the arctic coastal plain.	*Salix planifolia/S. rotundifolia-S. phlebophylla-Petasites frigidus-Poa arctica-Luzula confusa* (Clebsch 1957)

Preliminary Classification for Alaska Vegetation (Continued)

Level I	Level II	Level III	Level IV	Level V
2. Tundra (continued)	D. Shrub tundra (continued)	(2) Birch and ericaceous shrubs	a. Birch and ericaceous shrubs-sedge — is common in interior and northern Alaska.	*Betula nana-Ledum palustre-Vaccinium* spp.-*Carex bigelowii* (Bliss and Cantlon 1957; Churchill 1955; Hanson 1950, 1951) *Betula nana-Ledum palustre-Vaccinium* spp. *Empetrum nigrum-Eriophorum vaginatum-Carex bigelowii-Arctagrostis latifolia* (Churchill 1955)
			b. Birch and ericaceous shrubs-grass — may not be a very widespread type.	*Betula nana-Ledum palustre-Vaccinium vitis-idaea-Empetrum nigrum-Arctagrostis latifolia-Hierochloe alpina* (Churchill 1955) *Betula nana-Ledum palustre-Vaccinium vitis-idaea-Arctagrostis latifolia* (Churchill 1955)
			c. Birch and ericaceous shrubs-sphagnum — is widespread throughout northern and western Alaska.	*Betula nana-Ledum palustre-Vaccinium* spp.-*Rubus chamaemorus/Sphagnum* spp. (Drew and Shanks 1965; Fries 1977; Hanson 1953; Pegau and Hemming 1972; Webber et al. 1978; Young and Racine 1977) *Betula nana-Ledum palustre-Vaccinium vitis-idaea-Empetrum nigrum-Sphagnum* spp.-*Hylocomium* sp. (Young and Racine 1978; Palmer and Rouse 1945)
			d. Crowberry — is characteristic of southern Alaska and the Aleutian Islands.	*Empetrum nigrum-Cassiope stelleriana-Phyllodoce aleutica-Vaccinium* spp. (Cooper 1942; Heusser 1960) *Empetrum nigrum-Vaccinium* spp.-*Ledum palustre-Betula nana* (Griggs 1936; Racine and Young 1978) *Empetrum nigrum-Lycopodium* spp./*Brachythecium albicans-Cladonia* spp. (Bank 1951) *Empetrum nigrum-Carex pluriflora-C. macrochaeta/Cladonia* spp. (Bank 1951; Everett 1971; Hultén 1960; Shacklette et al. 1969) *Empetrum nigrum-Cassiope lycopodioides-Carex circinnata*/mosses (Byrd and Woolington 1977) *Empetrum nigrum-Arctostaphylos alpina* (Fries 1977) *Empetrum nigrum-Vaccinium uliginosum* (Hultén 1962)
			e. Ericaceous shrubs — are abundant in most areas of the State except north of the Brooks Range.	*Ledum palustre-Vaccinium* spp.-*Arctostaphylos alpina-Cassiope tetragona* (Johnson et al. 1966; Pegau and Hemming 1972) *Vaccinium* spp.-*Ledum palustre-Empetrum nigrum-Arctostaphylos alpina*/lichens (Hettinger and Janz 1974) *Vaccinium vitis-idaea-Empetrum nigrum/Cladina* spp. (Racine and Anderson 1979) *Vaccinium uliginosum-Diapensia lapponica-Phyllodoce coerulea-Salix polaris-S. arctica* (Fries 1977) *Phyllodoce aleutica-Vaccinium* spp.-*Cassiope stelleriana-Empetrum nigrum* (Isleib and Kessel 1973; Palmer 1942) *Phyllodoce aleutica-Cassiope stelleriana* (Heusser 1960) *Phyllodoce aleutica-Cassiope* spp.-*Vaccinium* spp. (Klein 1965, Ward 1957) *Cassiope mertensiana-C. stelleriana-Empetrum nigrum* (Heusser 1954, 1960) *Phyllodoce aleutica-Cassiope mertensiana* (Jaques 1973)

		f. Undifferentiated understory – is a common type found in all areas of the State.	*Betula nana-Ledum palustre-Vaccinium* spp. (Batten 1977, Koranda 1960; Ugolini and Walters 1974; Webber et al. 1978; Williamson and Peyton 1962) *Betula nana-Vaccinium* spp.-*Empetrum nigrum* (Hultén 1966) *Betula nana-Ledum palustre-Empetrum nigrum/Cladonia* spp.-*Stereocaulon* spp. (Young and Racine 1978)
	(3) Mixed shrub	a. Mixed shrub-grass – may be a relatively rare type.	*Salix glauca-Arctostaphylos rubra-Vaccinium uliginosum-Arctagrostis latifolia* (Hettinger and Janz 1974)
		b. Undifferentiated understory – is apparently a common type found in all tundra areas of the State.	*Betula nana-Ledum palustre-Vaccinium* spp.-*Salix planifolia* (Hanson 1953; Johnson et al. 1966; Koranda 1960) *Betula nana-Ledum palustre-Vaccinium* spp.-*Salix planifolia/Cladonia* spp.-*Cetraria* spp. (Hanson 1953; Pegau 1968) *Betula nana-Arctostaphylos alpina-Salix arctica-Dryas integrifolia* (Drew and Shanks 1965) *Betula nana-Vaccinium uliginosum-Salix reticulata-Dryas integrifolia-Cassiope tetragona* (Hettinger and Janz 1974) *Salix glauca-Dryas octopetala-Betula nana* (Hettinger and Janz 1974)
E. Mat and cushion tundra	(1) Open mat and cushion	a. Snowbed – occurs in alpine draws and on lee slopes where snow accumulates.	*Luetkea pectinata-Phyllodoce aleutica-Cassiope* spp. (Racine and Young 1978; Streveler et al. 1973) *Salix rotundifolia* (Klein 1958; Komárková and Webber 1978; White et al. 1975) *Salix rotundifolia-Oxyria digyna* (Anderson 1974)
		b. Dryas-lichen – is widespread in northern and western Alaska.	*Dryas octopetala*-lichens (Anderson 1974; Childs 1969; George et al. 1977; Hanson 1951; Spetzman 1959) *Dryas integrifolia*-lichens (Drew and Shanks 1965; Hanson 1951; Komárková and Webber 1978; Webber and Walker 1975) *Dryas octopetala*-lichens-*Oxytropis nigrescens-Salix phlebophylla-Carex microchaeta* (Johnson et al. 1966) *Dryas octopetala-Stereocaulon tomentosum* (Scott 1974) *Dryas octopetala-Cetraria cucullata*-other lichens-*Rhacomitrium lanuginosum* (Scott 1974) *Dryas octopetala-Empetrum nigrum-Salix arctica-Cetraria* spp. *Cladonia* spp. (Young and Racine 1978)
		c. Dryas-herb – is common on dry exposed sites throughout the State.	*Dryas octopetala-Minuartia* spp.-*Saxifraga* spp. (Hettinger and Janz 1974; Nodler et al. 1978) *Dryas octopetala-Astragalus* spp.-*Hedysarum alpinum* (Hanson 1953; Johnson et al. 1966) *Dryas integrifolia-Oxytropis nigrescens-Carex rupestris* (Koranda 1960; Webber and Walker 1975) *Dryas integrifolia-Lupinus arcticus* (Churchill 1955) *Dryas integrifolia-Hedysarum alpinum-Festuca rubra* (Hanson 1951) *Dryas drummondii-D. integrifolia-Astragalus* spp.-*Oxytropis campestris-Hedysarum mackenzii* (Viereck 1966)

Preliminary Classification for Alaska Vegetation (Continued)

Level I	Level II	Level III	Level IV	Level V
2. Tundra (continued)	E. Mat and cushion tundra (continued)	(1) Open mat and cushion (continued)	d. Dryas-sedge — is common on dry exposed sites throughout the State.	*Dryas octopetala-Carex microchaeta* (Webber et al. 1978) *Dryas octopetala-Carex misandra-C. bigelowii* (Hanson 1951) *Dryas octopetala-Carex glacialis* (Gjaerevoll 1954) *Dryas octopetala-Carex nardina-C. vaginata*-lichen (George et al. 1977) *Dryas integrifolia-Carex scirpoidea-Kobresia simpliciuscula* (Koranda 1960)
			e. Willow — generally occurs on stony soils, from south-central Alaska north and west.	*Salix rotundifolia* (Webber 1978) *Salix ovalifolia* (Webber et al. 1978; White et al. 1975) *Salix reticulata-Carex microchaeta-Rhacomitrium lanuginosum* (Hettinger and Janz 1974) *Salix reticulata-Carex saxatilis* (Hettinger and Janz 1974) *Salix rotundifolia-Potentilla vahliana-Saxifraga oppositifolia* (Racine and Anderson 1979) *Salix polaris-Cetraria islandica-Cladina rangiferina* (Scott 1974) *Salix arctica-Carex nesophila-Cladina alpestris-Cetraria cucullata* (Klein 1958) *Salix arctica-S. rotundifolia-Empetrum nigrum* (Shacklette et al. 1969) *Salix rotundifolia-S. ovalifolia-Cassiope lycopodioides-Empetrum nigrum* (Shacklette et al. 1969)
			f. Ericaceous shrubs — occur in shallow, stony soils in the mountains or at low elevations.	*Vaccinium vitis-idaea-Salix phlebophylla-Arctostaphylos alpina* (Anderson 1974) *Ledum palustre-Salix reticulata-Dryas octopetala-Empetrum nigrum-Poa alpina* (Hettinger and Janz 1974) *Loiseleuria procumbens-Vaccinium uliginosum-Salix arctica-Ledum palustre* (Griggs 1936)
			g. Open lichen — occurs on extremely harsh, windblown rocky sites with little or no soil development.	*Umbilicaria* spp.-*Rhizocarpon* spp. (Anderson 1974; Hanson 1953; Kessel and Schaller 1960; Klein 1958; Pegau 1968; Rausch and Rausch 1968; Webber et al. 1978) *Cladina* spp.-*Cetraria* spp.-*Stereocaulon* sp. (Johnson et al. 1966)
		(2) Closed mat and cushion	a. Prostrate shrubs and herbs on flood plains — occur along rivers in interior Alaska, northward and westward.	*Dryas integrifolia-Poa glauca-Oxytropis borealis* (Koranda 1960) *Dryas octopetala-Anemone drummondii-Lesquerella arctica-Crepis nana* (Drew and Shanks 1965)
			b. Mat and cushion-sedge — is found in all sections of Alaska except southeastern.	*Dryas octopetala-Carex scirpoidea* (Gjaerevoll 1954) *Dryas octopetala-Kobresia myosuroides* (Drew and Shanks 1965; Johnson et al. 1966; Spetzman 1959) *Dryas octopetala-Kobresia simpliciuscula* (Gjaerevoll 1954) *Dryas octopetala-Vaccinium vitis-idaea-Luzula* spp.-*Carex misandra* (Childs 1969) *Dryas octopetala-Carex franklinii* (Gjaerevoll 1954) *Dryas octopetala-Salix arctica-Carex bigelowii*-mosses (Anderson 1974)

	1950, 1953; Viereck 1963) *Salix reticulata-Dryas octopetala-Carex podocarpa* (Scott 1974) *Vaccinium uliginosum-Dryas octopetala-Carex bigelowii* (Anderson 1974) *Dryas integrifolia-Salix reticulata-Carex scirpoidea* (Batten 1977; Drew and Shanks 1965; Hettinger and Janz 1974) *Dryas integrifolia-Salix reticulata-Carex bigelowii* (Hettinger and Janz 1974) *Dryas integrifolia-Carex misandra-Rhytidium rugosum* (Hettinger and Janz 1974) *Dryas integrifolia-Vaccinium* spp.-*Carex* spp. (Drew and Shanks 1965) *Salix polaris-S. reticulata-Hylocomium splendens-Carex podocarpa* (Scott 1974)
c. Mat and cushion-grass — may not be a very abundant type.	*Vaccinium vitis-idaea-Dryas octopetala-Empetrum nigrum-Festuca altaica* (Scott 1974) *Salix ovalifolia-Empetrum nigrum-Festuca rubra-Calamagrostis deschampsioides* (Hanson 1951)
d. Dryas — is a very widespread type throughout Alaska except south-central and southeastern.	*Dryas octopetala* (Viereck 1963) *Dryas octopetala-Salix reticulata-Cassiope tetragona* (Anderson 1974; Batten 1977; Kessel and Schaller 1960; Viereck 1962a, 1963) *Dryas octopetala-Vaccinium uliginosum-Salix reticulata* (Anderson 1974) *Dryas octopetala-Arctostaphylos alpina* (Webber et al. 1978, Young 1974) *Dryas octopetala-Arctostaphylos alpina-Tomenthypnum nitens-Carex bigelowii* (Webber et al. 1978) *Dryas octopetala-Diapensia lapponica-Loiseleuria procumbens-Vaccinium vitis-idaea*-lichens (Racine and Young 1978) *Dryas octopetala-Cetraria* spp.-*Cladonia* spp. (Pegau 1968; Viereck 1962a) *Dryas integrifolia* (Komárková and Webber 1978, 1980; Webber and Walker 1975) *Dryas integrifolia-Cassiope tetragona* (Komárková and Webber 1978, 1980; Koranda 1960) *Dryas integrifolia-Arctostaphylos rubra* (Koranda 1960; Webber et al. 1978)
e. Cassiope — is a widespread type, usually in relatively mesic or shaded settings, in interior, western, and northern Alaska.	*Cassiope tetragona* (Anderson 1974; Komárková and Webber 1978, 1980; Pegau 1968; Scott 1974; Webber et al. 1978) *Cassiope tetragona-Salix rotundifolia*-mosses (Batten 1977, Webber and Walker 1975) *Cassiope tetragona-Vaccinium uliginosum*-mosses (Hanson 1953; Scott 1974) *Cassiope tetragona-Vaccinium vitis-idaea* (Childs 1969, Webber et al. 1978)

Preliminary Classification for Alaska Vegetation (Continued)

Level I	Level II	Level III	Level IV	Level V
2. Tundra (continued)	E. Mat and cushion tundra (continued)	(2) Closed mat and cushion (continued)	f. Bearberry — is common on the Seward Peninsula.	*Arctostaphylos alpina-Vaccinium vitis-idaea* (Hanson 1953) *Arctostaphylos alpina-Rhododendron camtschaticum* (Pegau 1968) *Arctostaphylos rubra-Cladonia* (Webber et al. 1978)
3. Shrub-land	A. Tall shrub	(1) Closed tall shrub	a. Willow — (sometimes called willow thickets) is especially characteristic of flood plains and common in interior, western, and northern Alaska.	*Salix alaxensis* (Bliss and Cantlon 1957; Griggs 1936; Hanson 1953; Johnson et al. 1966; Pegau and Hemming 1972; Spetzman 1959; Viereck 1963) *Salix alaxensis-S. glauca-S. lanata* (Drew and Shanks 1965, Komárková and Webber 1980; Spetzman 1959; Wiggins and Thomas 1962; Young 1974) *Salix alaxensis-S. planifolia* (Johnson et al. 1966; Young and Racine 1977) *Salix alaxensis-S. arbusculoides-S. glauca/Equisetum arvense-Pyrola grandiflora* (Batten 1977; Bliss and Cantlon 1957) *Salix alaxensis-S. arbusculoides/Calamagrostis canadensis-Equisetum pratense* (Hultén 1966) *Salix planifolia* (Hopkins and Sigafoos 1951; Hultén 1962, Johnson et al. 1966) *Salix glauca-S. planifolia-S. lanata* (Batten 1977; Childs 1969; Griggs 1936; Hanson 1953; Koranda 1960; Pegau 1968; Racine and Anderson 1979; Racine 1977; Viereck 1962a) *Salix barclayi* (del Moral and Watson 1978; Hultén 1960) *Alnus crispa/Calamagrostis canadensis* (Young and Racine 1977)
			b. Alder — closed *Alnus sinuata* communities are common in south-central and southeastern Alaska. In southwestern, northwestern, and interior Alaska, closed stands of *Alnus crispa* are common.	*Alnus crispa/Calamagrostis canadensis* (Hanson 1953; Viereck 1962a) *Alnus crispa-Salix arbusculoides-S. glauca/Delphinium glaucum-Aconitum delphinifolium-Calamagrostis* spp. (Viereck 1963) *Alnus sinuata* (Cooper 1942; Palmer 1942; Young and Racine 1978) *Alnus sinuata/Calamagrostis canadensis* (Hultén 1960, 1962) *Alnus sinuata/Rubus spectabilis* (Heusser 1960; Isleib and Kessel 1973; Streveler and Paige 1971) *Alnus tenuifolia/Calamagrostis canadensis* (Hanson 1953)
			c. Shrub birch — is generally found in openings in taiga in interior Alaska near tree line.	*Betula glandulosa* (Hanson 1953)
			d. Alder-willow — occurs on flood plain terraces and drainageways on slopes.	*Alnus crispa-Salix planifolia/Carex bigelowii* (George et al. 1977; Racine and Anderson 1979) *Alnus crispa-Salix glauca/Arctagrostis latifolia-Pyrola grandiflora* (Churchill 1955) *Alnus crispa-Salix lanata-S. planifolia-S. glauca* (Bliss and Cantlon 1957)
			e. Shrub birch-willow — is apparently not a very common type but present on the Seward Peninsula.	*Betula glandulosa-Salix planifolia-S. lanata-Alnus crispa* (Hanson 1953)

	(2) Open tall shrub	banks, most common in interior, western, and northern Alaska.	*Salix alaxensis/Arctostaphylos rubra* (Webber et al. 1978) *Salix alaxensis/Astragalus alpinus-Epilobium latifolium* (Webber et al. 1978) *Salix alaxensis/Shepherdia canadensis/Dryas octopetala-Arctostaphylos rubra-Cladonia pyxidata* (Scott 1974) *Salix brachycarpa-S. barclayi-S. glauca/Hylocomium splendens* (Viereck 1966) *Salix planifolia-S. glauca/Calamagrostis canadensis-Epilobium angustifolium-Equisetum pratense* (Young and Racine 1978)
		b. Alder — is not nearly as abundant as closed alder communities but can be found throughout the State.	*Alnus crispa/Calamagrostis canadensis* (Young and Racine 1977)
		c. Shrub birch — occurs at and above tree line, especially in the Alaska Range.	*Betula glandulosa/Ledum palustre-Vaccinium* spp.-*Arctostaphylos alpina-Festuca altaica* (Batten et al. 1979)
		d. Alder-willow — occurs on flood plain terraces and steep slopes near tree line in interior and northern Alaska.	*Alnus crispa-Salix lanata-S. planifolia/Ledum palustre-Carex bigelowii/Sphagnum* spp. (Viereck 1963)
		e. Shrub birch-willow — occurs in the tree line zone, especially in the Alaska Range and western Alaska; this type has not yet been described.	
8. Low shrub	(1) Closed low shrub	a. Dwarf birch — thickets are not common but do occur on the Seward Peninsula and in interior Alaska.	*Betula nana* (Hopkins and Sigafoos 1951; Racine and Anderson 1979) *Betula glandulosa/Pleurozium schreberi-Hylocomium splendens* (Viereck 1966)
		b. Low willow — is common in interior, western, and northern Alaska.	*Salix planifolia/Equisetum arvense* (Webber et al. 1978) *Salix glauca-S. planifolia-S. lanata* (Pegau 1968; Racine 1977)
		c. Dwarf birch-willow — has not yet been described.	
	(2) Open low shrub	a. Dwarf birch — is common in the Alaska Range and on the Seward Peninsula.	*Betula glandulosa/Hylocomium splendens* (Hettinger and Janz 1974; Viereck 1966) *Betula glandulosa/Vaccinium uliginosum-Carex bigelowii/Aulacomnium palustre-Hylocomium splendens* (Scott 1974) *Betula glandulosa/Vaccinium uliginosum-Ledum palustre/Cladonia-Cetraria* (Kessel and Schaller 1960; Pegau 1968) *Betula glandulosa/Vaccinium uliginosum-Festuca altaica/Dryas integrifolia-Salix reticulata-Cetraria cucullata-Cladonia* spp. (Viereck 1962b) *Betula glandulosa/Ledum palustre-Vaccinium vitis-idaea* (Anderson 1974)
		b. Low willow — is common in interior, northern, and western Alaska.	

Preliminary Classification for Alaska Vegetation (Continued)

Level I	Level II	Level III	Level IV	Level V
3. Shrub-land (continued)	8. Low shrub (continued)	(2) Open low shrub (continued)	b. Low willow — is common in interior, northern, and western Alaska.	*Salix planifolia/Carex bigelowii-Petasites frigidus/Hylocomium splendens* (Hettinger and Janz 1974) *Salix planifolia/Carex podocarpa-Petasites frigidus* (Anderson 1974) *Salix planifolia/Carex bigelowii-Arctagrostis latifolia* (Churchill 1955) *Salix glauca/Petasites frigidus* (Churchill 1955) *Salix glauca/Dryas octopetala* (Webber et al. 1978) *Salix glauca/S. reticulata-Carex podocarpa-Artemisia arctica* (Scott 1974) *Salix glauca/Arctostaphylos rubra-Dryas octopetala-Salix reticulata-Oxytropis deflexa* (Scott 1974) *Salix glauca/Arctostaphylos alpina* (Webber et al. 1978) *Salix lanata-S. glauca/Dryas integrifolia* (Komárková and Webber 1980) *Salix lanata/Equisetum arvense* (Webber et al. 1978)
			c. Dwarf birch-willow — is present in interior and northern Alaska.	*Betula nana-Salix brachycarpa-S. planifolia-S. lanata/Arctostaphylos rubra-Cassiope tetragona-Ledum palustre* (Spetzman 1959) *Salix arbusculoides-S. glauca-S. hastata-Betula glandulosa/Bromus pumpellianus-Festuca altaica* (Batten 1977) *Betula glandulosa-Salix glauca-S. planifolia/Festuca altaica-Vaccinium vitis-idaea-Arctostaphylos alpina/Hylocomium splendens* (Viereck 1963) *Salix glauca-Betula nana* (Childs 1969)
			d. Low alder — *Alnus crispa* forms low thickets at the north edge of its range in the Brooks Range and arctic foothills.	*Alnus crispa/Vaccinium uliginosum Ledum palustre-Betula nana-Carex bigelowii/Hylocomium splendens-Aulacomnium palustre* (Bliss and Cantlon 1957)
			e. Low alder-willow — is an uncommon type found on flood plains in northern Alaska, at the northern edge of the range of alder.	*Alnus crispa-Salix* spp./*Carex bigelowii-Empetrum nigrum-Vaccinium vitis-idaea/Cetraria cucullata-Cladonia* spp. (Bliss and Cantlon 1957)
			f. Shepherdia-dryas — occurs on flood plains in interior Alaska.	*Shepherdia canadensis/Dryas octopetala* (Scott 1974)
			g. Dwarf birch-sphagnum — has not yet been described in Alaska.	
			h. Mixed shrub-sphagnum — is common in interior and western Alaska.	*Betula nana-Ledum palustre-Vaccinium vitis-idaea-Carex* spp.-*Rubus chamaemorus/Sphagnum* spp. (Hanson 1953) *Empetrum nigrum-Vaccinium* spp.-*Carex pluriflora-Rubus chamaemorus/Sphagnum* spp. (Hultén 1960) *Myrica gale-Betula glandulosa/Carex kelloggii-Rubus chamaemorus/Sphagnum* spp. (Griggs 1936)

ceous vegetation		for southeastern and northern Alaska; occupies large areas in south-central and southwestern Alaska.	*Calamagrostis canadensis* (Bank 1951; Fries 1977; Hanson 1953; Heusser 1960; Hultén 1966; Pegau and Hemming 1972) *Calamagrostis nutkaensis/Festuca rubra* (Amundsen and Clebsch 1971; Byrd and Woolington 1977)
	(2) Bluejoint-herb	a. Bluejoint-fireweed — is widely distributed in the southern half of the State. It thrives in disturbed areas.	*Calamagrostis canadensis-Epilobium angustifolium* (Hanson 1951; Klein 1958; Young and Racine 1978)
		b. Bluejoint-mixed herbs — are moist to wet meadow types located in southwestern, south-central, and southeastern Alaska.	*Calamagrostis canadensis-Epilobium angustifolium-Geranium erianthum* (Heusser 1960) *Calamagrostis canadensis-Thalictrum minus-Geranium erianthum-Epilobium angustifolium* (Hultén 1960) *Calamagrostis canadensis-Epilobium angustifolium-Heracleum lanatum-Angelica genuflexa* (Griggs 1936) *Calamagrostis canadensis-Deschampsia beringensis-Heracleum lanatum-Angelica lucida* (Bank 1951)
	(3) Bluejoint-shrub	a. Bluejoint-alder — is extensive in southwestern Alaska but virtually unknown throughout the rest of the State.	*Calamagrostis canadensis-Alnus sinuata* (Griggs 1936)
	(4) Herbs	a. Mixed herbs — occur on mesic slopes and streambanks from south-central Alaska to the Aleutian Islands.	*Aconitum delphinifolium-Aquilegia formosa-Sanguisorba stipulata-Geranium erianthum* (Cooper 1942) *Streptopus amplexifolius-Linnaea borealis-Juncus arcticus* (Bank 1951) *Platanthera* spp.-*Fritillaria camschatcensis-Polygonum viviparum-Erigeron peregrinus* (Bank 1951) *Athyrium filix-femina-Carex lyngbyaei-Heracleum lanatum-Geum macrophyllum* (Shacklette et al. 1969) *Potentilla egedii-Festuca rubra* (del Moral and Watson 1978)
		b. Fireweed — occurs on disturbed areas in south-central and southeastern Alaska.	*Epilobium angustifolium*
		c. Cow parsnip — occurs on moist to wet areas, often along drainages, in southeastern and south-central Alaska and the Aleutian Islands.	*Heracleum lanatum-Veratrum viride-Senecio triangularis* (Cooper 1942) *Heracleum lanatum-Athyrium filix-femina-Angelica lucida/Claytonia sibirica/Cardamine umbellata-Coptis trifolia/* mosses (Byrd and Woolington 1977)
		d. Ferns — are restricted to localized areas in southeastern and south-central Alaska and in the Aleutian Islands.	*Athyrium filix-femina-Cystopteris fragilis-Botrychium* spp. *Gymnocarpium dryopteris* (Bank 1951)
	(5) Elymus	a. Coastal elymus — grows on beaches out of reach of normal tides along the entire Alaska coastline.	*Elymus arenarius* (Bank 1951; George et al. 1977; Griggs 1936; Hanson 1953; Klein 1958; Shacklette et al. 1969; Spetzman 1959; Stephens and Billings 1967; Ugolini and Walters 1974; Young 1971)

Preliminary Classification for Alaska Vegetation (Continued)

Level I	Level II	Level III	Level IV	Level V
4. Herbaceous vegetation (continued)	A. Tall grass (continued)	(5) Elymus (continued)	b. Coastal elymus-herb — has approximately the same distribution as the coastal elymus type.	*Elymus arenarius-Honckenya peploides-Mertensia maritima* (Fries 1977; Johnson et al. 1966; Potter 1972; Wiggins and Thomas 1962) *Elymus arenarius-Senecio pseudoarnica-Lathyrus maritimus* (Bank 1951; Hultén 1960; Rausch and Rausch 1968) *Elymus arenarius-Lathyrus maritimus-Poa eminens* (Hanson 1953) *Elymus arenarius-Ligusticum scoticum-Anemone narcissiflora* (Shacklette et al. 1969) *Elymus arenarius-Heracleum lanatum-Claytonia sibirica* (Byrd and Woolington 1977)
			c. Dune elymus — is common on dune systems, usually on or near the coast.	*Elymus arenarius-Festuca rubra* (Palmer and Rouse 1945) *Elymus arenarius-Lathyrus maritimus-Senecio pseudoarnica-Angelica lucida* (Fries 1977) *Elymus arenarius-Polemonium boreale-Senecio pseudoarnica* (Young and Racine 1978) *Elymus arenarius-Dryas integrifolia* (Komárková and Webber 1980)
			d. Inland shore elymus — occurs on gravel outwash flats and lake beach ridges on the Seward Peninsula	*Elymus arenarius* (Racine and Anderson 1979)
	B. Midgrass	(1) Dry midgrass	a. Dry elymus — is a relatively uncommon type that occurs in the Alaska Range and possibly in interior Alaska and the Brooks Range.	*Elymus innovatus-Festuca altaica/Hylocomium splendens* (Viereck 1966) *Elymus innovatus-Poa glauca* (Hanson 1951)
			b. Grass-shrub — is common on localized, steep, south-facing bluffs in interior and south-central Alaska	*Festuca altaica-Salix lanata-Artemisia arctica* (Scott 1974) *Calamagrostis purpurascens-Artemisia frigida* (Hanson 1951) *Festuca altaica-Vaccinium vitis-idaea-V. uliginosum-Dryas octopetala* (Hanson 1951) *Festuca altaica-Empetrum nigrum-Salix reticulata* (Scott 1974)
			c. Dry bluejoint — is a bluejoint type of low stature occurring on dry sites, especially near the northern and western limits of the range of bluejoint.	*Calamagrostis canadensis* (Burns 1964; Hanson 1953; Pegau 1968)
			d. Dry fescue — occupies dry slopes in interior, south-central, and western Alaska.	*Festuca altaica* (Hanson 1951, 1953) *Festuca altaica-Calamagrostis canadensis* (Hanson 1951)

		meadows to streambanks. It is found in the Aleutian Islands and in southwestern, south-central, and interior Alaska.	and Hemming 1972) *Festuca altaica-Lupinus arcticus* (Scott 1974) *Festuca altaica-Carex podocarpa-Aconitum delphinifolium-Mertensia paniculata-Artemisia arctica* (Hanson 1951) *Festuca altaica-Sanguisorba stipulata-Lycopodium alpinum-Salix reticulata/Hypnaceae* (Hanson 1951) *Festuca altaica-Calamagrostis canadensis-Cornus canadensis-Geranium erianthum* (Hanson 1951) *Festuca rubra-Angelica lucida-Achillea borealis-Cardamine umbellata* (Byrd and Woolington 1977) *Poa eminens-Deschampsia beringensis-Festuca rubra* (Shacklette et al. 1969)
		b. Hair-grass – is common in the Aleutian Islands and along the southern coast of Alaska.	*Deschampsia beringensis* (Hanson 1951)
C. Sedge-grass	(1) Wet sedge-grass (fresh water)	a. Sedge marsh – occurs primarily in the southern part of the State and in the Aleutian Islands.	*Carex lyngbyaei* (Batten et al. 1978; Byrd and Woolington 1977; Griggs 1936; Hultén 1960) *Carex nigricans-C. limosa* (Cooper 1942) *Carex pluriflora-Trichophorum caespitosum-Eriophorum russeolum-Polygonum viviparum-Erigeron peregrinus* (Bank 1951) *Carex rostrata-Eriophorum angustifolium-Calamagrostis canadensis-Cicuta mackenzieana* (Young and Racine 1978) *Carex lyngbyaei-C. pluriflora-C. anthoxanthea-C. macrochaeta* (Shacklette et al. 1969) *Carex pluriflora* (Batten et al. 1978) *Scirpus validus* (Batten et al. 1978; del Moral and Watson 1978) *Carex mackenziei* (del Moral and Watson 1978)
		b. Moss-sedge marsh – occurs primarily in southeastern and south-central Alaska and in the Aleutian Islands.	*Scapania paludosa-Nardia scalaris-Marsupella emarginata* (Shacklette et al. 1969) *Philonotis fontana-Parnassia kotzebuei* (Shacklette et al. 1969) *Sphagnum teres-S. squarrosum-S. magellanicum-S. compactum-S. papillosum-S. girgensohnii* (Shacklette et al. 1969)
		c. Herb marsh – is a rare type that has been reported from the Aleutian Islands.	*Caltha palustris-Claytonia sibirica* (Shacklette et al. 1969)
	(2) Saline sedge-grass (tidal marsh)	a. Halophytic grass – occurs on sheltered, gently sloping sites with silty substrates along the entire Alaska coastline.	*Puccinellia phryganodes* (Jefferies 1977) *Puccinellia langeana* (Griggs 1936) *Puccinellia nutkaensis* (Batten et al. 1978) *Puccinellia grandis* (Batten et al. 1978)
		b. Halophytic sedge – occurs on sheltered sites along the Alaska coastline.	*Carex lyngbyaei* (Batten et al. 1978; del Moral and Watson 1978; Stephens and Billings 1967) *Carex subspathacea* (Hanson 1951) *Carex subspathacea-Puccinellia phryganodes* (Webber et al. 1978) *Carex ramenskii* (Batten et al. 1978; Jefferies 1977) *Carex ramenskii-Potentilla egedii* (George et al. 1977) *Eleocharis palustris* (del Moral and Watson 1978)

Preliminary Classification for Alaska Vegetation (Continued)

Level I	Level II	Level III	Level IV	Level V
4. Herbaceous vegetation (continued)	C. Sedge-grass (continued)	(2) Saline sedge-grass (tidal marsh) (continued)	c. Halophytic herbs — are generally located seaward from the band of *Elymus arenarius*.	*Mertensia maritima-Honckenya peploides* (Amundsen and Clebsch 1971; Britton 1967; Griggs 1936; Hanson 1953, Potter 1972; Spetzman 1959; Thomas 1951) *Cochlearia officinalis* (Wiggins and Thomas 1962) *Cochlearia officinalis-Lathyrus maritimus* (Bank 1951) *Cochlearia officinalis-Puccinellia phryganodes* (Webber et al. 1978) *Honckenya peploides-Senecio pseudoarnica* (Shacklette et al. 1969; Young 1971) *Cochlearia officinalis-Achillea borealis-Draba hyperborea* (Byrd and Woolington 1977) *Plantago maritima-Triglochin maritimum-Puccinellia* spp. (Batten et al. 1978) *Cochlearia officinalis-Fucus distichus* (Batten et al. 1978) *Juncus arcticus* (del Moral and Watson 1978)
		(3) Mesic sedge-grass	a. Sedge-grass — is found in south-central Alaska and on the Aleutian Islands.	*Calamagrostis canadensis-Carex macrochaeta* (Hanson 1951) *Carex macrochaeta-Festuca rubra* (Byrd and Woolington 1977)
			b. Sedge — is found on the Aleutian Islands.	*Carex lyngbyaei-C. macrochaeta-Cladina impexa* (Shacklette et al. 1969
5. Aquatic vegetation	A. Freshwater	(1) Ponds and lakes	a. Floating and submerged vegetation — is common throughout the State, except rare on the arctic coastal plain.	*Ranunculus trichophyllus-Hippuris vulgaris* (Hanson 1953; Shacklette et al. 1969) *Sparganium hyperboreum-Potamogeton perfoliatus* (Hultén 1960, 1966) *Potamogeton* spp.-*Myriophyllum spicatum* (Batten et al. 1978) *Ranunculus hyperboreus-R. gmelini-R. trichophyllus* (Johnson et al. 1966) *Nuphar polysepalum* (Batten et al. 1978; Griggs 1936) *Isoetes muricata-Ranunculus reptans-Limosella aquatica* (Shacklette et al. 1969) *Siphula ceratites-Scapania paludosa* (Shacklette et al. 1969) *Subularia aquatica-Callitriche anceps* (Shacklette et al. 1969)
			b. Emergent vegetation — is common throughout the State.	*Arctophila fulva* (Clebsch 1957; Komárková and Webber 1978, 1980; Potter 1972; Rausch and Rausch 1968; Webber 1978, Webber and Walker 1975; Wiggins and Thomas 1962) *Arctophila fulva-Hippuris vulgaris-Ranunculus pallasii-Potentilla palustris* (Johnson et al. 1966) *Hippuris vulgaris* (Potter 1972) *Menyanthes trifoliata-Ranunculus pallasii* (Webber et al. 1978) *Cicuta mackenzieana-Hippuris vulgaris-Menyanthes trifoliata-Equisetum fluviatile* (Hultén 1966)

			Ranunculus hyperboreus-R. trichophyllus (Griggs 1936)
		b. Emergent vegetation — is common throughout the State.	*Arctophila fulva* (Hultén 1966) *Potentilla palustris-Menyanthes trifoliata-Caltha palustris* (Griggs 1936)
B. Saltwater	(1) Estuarine		
	(2) Intertidal		

Key to Levels I, II, and III of the Proposed Classification of Alaska Vegetation

Although the classification is based primarily on the vegetation, it was necessary to use location and site characteristics for key characteristics in some instances. When more quantitative information is available on the plant communities it should be possible to separate the types based only on vegetation characteristics. Since the aquatic vegetation classification has not been developed, this key includes only the four terrestrial classes.

1. Trees present and with canopy cover of 10 percent or more .... 1 *Forest* .... 2.
1. Trees absent or nearly so, with less than 10-percent cover .... 9.
2. Over 75 percent of tree cover contributed by conifer species .... 1-A *Conifer forest* .... 3.
2. Less than 75 percent of tree cover contributed by conifer species .... 5.
3. Tree canopy of 60- to 100-percent cover .... 1-A-(1) *Closed conifer forest*
3. Tree canopy of less than 60-percent cover .... 4.
4. Tree canopy of 25- to 59-percent cover .... 1-A-(2) *Open conifer forest*
4. Tree canopy of 10- to 24-percent cover .... 1-A-(3) *Conifer woodland*
5. Over 75 percent of tree cover contributed by deciduous species .... 1-B *Deciduous forest* .... 6.
5. Deciduous or conifer species contribute 25 to 74 percent of tree cover .... 1-C *Mixed conifer and deciduous forest* .... 8.
6. Tree canopy of 60- to 100-percent cover .... 1-B-(1) *Closed deciduous forest*
6. Tree canopy of less than 60-percent cover .... 7.
7. Tree canopy of 25- to 59-percent cover .... 1-B-(2) *Open deciduous forest*
7. Tree canopy of 10- to 24-percent cover .... 1-B-(3) *Deciduous woodland*
8. Tree canopy of 60- to 100-percent cover .... 1-C-(1) *Closed mixed forest*
8. Tree canopy of 25- to 59-percent cover .... 1-C-(2) *Open mixed forest*
9. Vegetation dominated by erect to decumbent (but not matted) woody shrubs; shrub cover at least 25 percent .... 3 *Shrubland* and 2-D *Shrub tundra* .... 10.
9. Vegetation herbaceous or of low, cushionlike shrubs, less than 20 centimeters (8 inches) in height; taller shrubs if present with less than 25-percent cover 14
10. Shrubs more than 1.5 meters (5 feet) tall .... 3-A *Tall shrubland* 12
10. Shrubs less than 1.5 meters (5 feet) tall 11
11. Shrubs associated with typical tundra sedges, herbs, and mosses. Located in areas above or beyond the limit of trees .... 2-D *Shrub tundra* 25
11. Shrubs not associated with tundra species. Located adjacent to tree line or in forested region .... 3-B *Low shrubland* 13
12. Shrub canopy cover greater than 75 percent .... 3-A-(1) *Closed tall shrubland*
12. Shrub canopy cover 25 to 75 percent .... 3-A-(2) *Open tall shrubland*
13. Shrub canopy cover greater than 75 percent .... 3-B-(1) *Closed low shrubland*
13. Shrub canopy cover 25 to 75 percent .... 3-B-(2) *Open low shrubland*

14. Vegetation dominated by grass species, primarily *Calamagrostis* and *Elymus,* or if dominated by sedges and forbs, found primarily within forested areas . . . . . . 4 *Herbaceous vegetation* . . . . 27.

14. Vegetation dominated by sedges and low, matted shrubs; if grasses are dominant they are typical arctic species, such as *Arctagrostis latifolia* or *Poa arctica.* Found in areas above and beyond the limit of trees . . . . 2 *Tundra* . . . . 15.

15. Tussocks of *Eriophorum vaginatum* dominant . . . . 2-C *Tussock tundra* . . . . 16.

15. Tussock not dominant, vegetation dominated by a sedge-grass mat, by mat and cushion plants, or by forbs . . . . 17.

16. Tussock vegetation without interspersed shrubs . . . . 2-C-(1) *Sedge tussock tundra*

16. Tussock vegetation with scattered shrubs on and between the tussocks . . . . 2-C-(2) *Sedge tussock-shrub tundra*

17. Vegetation a sedge-grass mat – not forming tussocks . . . . 2-A *Sedge-grass tundra* . . . . 18.

17. Vegetation dominated by mat and cushion plants or forbs . . . . 22.

18. Dominated by sedges and grasses common to wet sites, primarily *Carex aquatilis, Eriophorum angustifolium,* or *Dupontia fischeri,* with or without shrubs . . . . 2-A-(1) *Wet sedge-grass tundra* and 2-A-(3) *Sedge-shrub tundra* . . . . 19.

18. On mesic sites, dominated by sedges, grasses, or forbs, such as *Poa arctica, Arctagrostis latifolia, Carex microchaeta, Carex nesophila, Carex bigelowii* . . . . 20.

19. Sedges dominate, but with up to 25-percent cover of willows or birch . . . . 2-A-(3) *Sedge-shrub tundra*

19. Sedges and grasses nearly pure with less than 10-percent shrub cover . . . . 2-A-(1) *Wet sedge-grass tundra*

20. With 10- to 25-percent cover of low or matted shrubs . . . . 21.

20. With less than 10-percent cover of low or matted shrubs . . . . 2-A-(2) *Mesic sedge-grass tundra*

21. With up to 25-percent cover of low shrubs of birch or willow . . . . 2-A-(3) *Sedge-shrub tundra*

21. With up to 25-percent cover of matted shrubs, such as *Dryas* and *Arctostaphylos* . . . . 2-A-(4) *Sedge-mat and cushion tundra*

22. Dominated by mat and cushion plants . . . . 2-E *Mat and cushion tundra* . . . . 23.

22. Dominated by forbs . . . . 2-B *Herbaceous tundra* . . . . 24.

23. At least 75 percent or more of the surface covered with plants . . . . 2-E-(2) *Closed mat and cushion tundra*

23. Less than 75 percent of the surface covered with plants . . . . 2-E-(1) *Open mat and cushion tundra*

24. Seral communities at low elevations in tundra areas – limited distribution . . . . 2-B-(1) *Low elevation herbaceous tundra*

24. Snow beds, cliffs, and scree slopes in alpine tundra areas – a diverse group . . . . 2-B-(2) *Alpine herbaceous tundra*

25. Dominated by low willows . . . . 2-D-(1) *Willow shrub tundra*

25. Dominated by birch, ericaceous shrubs, or a mixture of shrub species . . . . 26.

Key, continued

26. Dominated by birch and ericaceous shrubs . . . . 2-D-(2) *Birch and ericaceous shrub tundra*
26. Dominated by birch, ericaceous shrubs, and willows . . . . 2-D-(3) *Mixed shrub tundra*
27. Dominated by grasses but with occasional forbs and sedges . . . . 30.
27. Dominated by a nearly equal mixture of sedges, grasses, and forbs . . . . 4-C *Herbaceous sedge-grass* . . . . 28.
28. On wet sites, usually with some standing water . . . . 29.
28. On mesic sites . . . . 4-C-(3) *Mesic sedge-grass*
29. Growing in fresh water . . . . 4-C-(1) *Wet sedge-grass (fresh water)*
29. Growing in salty or brackish water . . . . 4-C-(2) *Saline sedge-grass (tidal marsh)*
30. Grasses at maturity over 1 meter (3.3 feet) in height . . . . 4-A *Tall grassland* . . . . 31.
30. Grasses at maturity less than 1 meter (3.3 feet) in height . . . . 35.
31. Dominants are species of *Calamagrostis* . . . . 32.
31. Dominants are *Elymus* and herbs . . . . 34.
32. Grass species nearly pure with less than 25-percent herbs . . . . 4-A-(1) *Bluejoint*
32. Grass mixed with at least 25-percent herbs and shrubs . . . . 33.
33. Grasses mixed with at least 25-percent cover of shrubs . . . . 4-A-(3) *Bluejoint-shrub*
33. Grasses mixed with at least 25-percent herbs . . . . 4-A-(2) *Bluejoint-herb*
34. Dominant cover is *Elymus arenarius* . . . . 4-A-(5) *Elymus*
34. Dominant cover is herbs . . . . 4-A-(4) *Herbs*
35. Found on dry, usually south-facing slopes . . . . 4-B-(1) *Dry midgrass*
35. Found on mesic sites . . . . 4-B-(2) *Mesic midgrass*

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Forest Regeneration at High Latitudes

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FOREST REGENERATION AT HIGH LATITUDES

Edited by
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INTRODUCTION

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Early in 1979 we surveyed forest managers and researchers in a number of northern countries to identify topics in forest management of circumpolar interest. Responses most frequently centered on problems of forest regeneration and related harvesting practices. As a result, an international workshop was held in Fairbanks, Alaska, on 13-15 November 1979, to obtain a perspective of forest regeneration at high latitudes.

Through support from the Forest Service, U.S. Department of Agriculture, and the Bureau of Land Management, U.S. Department of the Interior, the School of Agriculture and Land Resources Management, University of Alaska, brought together at the workshop foresters from Canada, Norway, Sweden, Finland and Alaska. Papers included in this report were presented at the workshop. Techniques for forest regeneration described in other northern countries may have applications in Alaska as demands increase for forest products and forest biomass as an energy source.

Subsequent workshops are planned in collaboration with the International Union of Forestry Research Organization to assess forest management techniques for the regeneration of white spruce in Alaska and the Yukon Territory. In the meantime, sincere appreciation is expressed to the authors of papers in this interim report of the working group that assembled in Fairbanks, Alaska, in November 1979.

DEVELOPING A PROGRAM FOR RESEARCH AND APPLIED MANAGEMENT

RELATED TO FOREST REGENERATION

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FOREST REGENERATION AND LEVELS OF MANAGEMENT

Forest regeneration includes a wide field of biological and technological aspects. The area of forest land in northern latitudes is rather limited in relation to the forest areas of the whole world, and the number of species especially, are small. However, northern latitudes involve increasing biological problems due to the forest growing so close to the alpine and polar tree limits.

There is reason to discuss whether or not all aspects ought to be considered in a research program on forest regeneration. First of all, should all areas on the northern latitude be involved? Even north of the 60th parallel the conditions for the growing forest vary rather considerably and quite a few tree species are involved. I have the feeling that a research program outlined for limited areas and selected species would be most fruitful and easier to carry out. Also for economical reasons it would not be possible to develop a research program covering all the different conditions and species. Consequently, as a starting point at least, I think we ought to discuss and decide which regions and species should be involved in a cooperative program of research and applied management.

If separate regions are chosen, the program should then contain selected items and problems most likely to be of paramount importance for the future forestry of these regions, up to the turn of the century. As applied management should be involved in the program, the research part of it should, as far as possible, cover the level of intensity of forest management to be expected in the future.

In general terms, three levels of future forestry can be mentioned with different consequences for applied research.

1. Harvesting merchantable trees and stands without concern for further development or yield. This is the low intensity level where the areas are left for a long period until nature has provided for merchantable trees again.

2. Harvesting merchantable trees in a way that secures a reasonable natural regeneration of valuable species, or enables remaining smaller trees to develop into merchantable dimensions. Medium intensity level.

3. Artificial regeneration (planting or sowing) immediately or soon after the harvesting cut, securing a good regeneration of the most important species. This is the high intensity level with no time wasted and the whole area producing good timber.

Management on the lowest level needs little or no research. Management on the medium level with natural regeneration depends greatly on climate, soil and species.

Climate of northern latitudes, especially summer temperature and length of growing season, is a limiting factor for flowering and ripening of seed. Low summer temperature also causes a low rate of humus decomposition, resulting in a thick layer of raw humus which is a poor bed for germinating seeds.

Besides climate, humus decomposition is influenced by soil conditions, especially the structure and moisture content. Small seedlings of conifers will receive strong competition from ground vegetation, varying with species and vigor of the plants. Scarification improves the seed bed and lessens the competition considerably.

By means of scarification, management based on natural regeneration may reach a fairly high level. The same is the case without scarification, for instance for pine on dry sandy soils with thin humus layers, where the natural regeneration will be abundant.

A condition for using natural regeneration is that one or more suitable species are present in the area. When introducing new species or provenances, artificial regeneration is required.

Within this complex of natural regeneration, there are plenty of questions suitable for applied research.

Management on the high level of intensity with artificial regeneration has few restrictions, this being the main reason why nearly all areas of medium and good spruce sites are artificially regenerated in Scandinavia as well as in northern Europe.

However, the cost of regeneration may be a limiting factor, especially in remote areas and in steep terrain where income from harvesting is greatly reduced by high costs for

cutting and transport. On the other hand, management planning is simpler, and advanced harvesting methods and machines can be used without such restrictions as size of cutting areas, leaving of seed trees or preventing damage on regeneration.

On some sites, where broad-leaved trees are very vigorous, a plantation of conifers has to be followed by tending, reducing the broad-leaved competition. This can be done by hand, machines or chemicals. Also management based on natural regeneration with scarification may need to fight the broad-leaved competition.

In such highly intensive management there are a multitude of questions calling for research.

It is not my task at present to draw any conclusions regarding regions or levels for a cooperative program for research and applied management. But the ideas presented here might be of interest when discussing and deciding upon which problems should go into a program. Such a program for research and applied management has, besides the intensity level, to a very great extent, to be based on the existing conditions for instance terrain, site, species, climate, etc.

FOREST REGENERATION IN NORWAY

The second part of this paper will give some information on forest regeneration as practiced in Norway where, in fact, all three intensity levels are used.

The mountain forests are managed according to intensity level 1 or something between 1 and 2. At least, in the upper belt of approximately 200 m adjacent to the timber line, artificial regeneration is seldom used. In addition to low density and lack of regeneration, the mountain forests are slow growing and not usually managed intensively. Cuttings are mostly made to salvage mature and dying trees.

Below this upper two hundred meter belt, the forests in Norway are usually managed. Of these forests about one third of the area is Scotch pine (*Pinus sylvestris* L.). In Norway the best pine sites are along the rivers on dry, sandy soils. The thin humus layer and sparse ground vegetation, mostly lichen, offer good conditions for natural regeneration of pine. There are also areas at high elevation with a site class most suitable for carrying pine where there are very few pine trees left. Such areas will be planted with pine although in Norway pine planting is less than 10% of the planting program. In Sweden and Finland however, planting pine is very common.

The main coniferous species of Norway is Norway spruce (*Picea abies* [L.] Karst.) which amounts to two thirds of all the forests of Norway. In addition, a large afforestation scheme for the coastal districts of Western Norway has been underway for the last thirty years. Native trees in this area are Scotch pine and some broad-leaved trees. For the afforestation up to 80% of Norway spruce is used, and Sitka spruce (*Picea sitchensis* [Bong.] Carr) is used in the outer, windy areas.

Generally, planting is the preferred method to establish spruce regeneration in Norway, except for the upper 200 m belt as mentioned. This means intensity levels 3 or in some smaller forests where natural conditions are very favorable, something between level 2 and 3.

There are several reasons for using planting:

1. The natural regeneration of Norway spruce very often comes slowly and scattered due to periodic seed-years and unfavorable germinating conditions in the raw humus layer. In addition, natural regeneration is often over-grown by broad-leaved trees, mostly birch.

2. When raising natural regeneration under shelter trees it is difficult to avoid damage to this regeneration when harvesting the shelter trees. This problem has been more pronounced due to the horse being substituted by increasingly bigger and heavier tractors causing much damage to the young regeneration.

3. Planning management is easier when planting is used to establish the new stand. Regeneration cutting can then be planned and carried out independent of seed years and germination conditions.

Another advantage is that the best provenances can be used to secure the most valuable yield in the future. In areas where it is preferable to change species, planting is the only solution, for instance Sitka spruce or lodgepole pine (*Pinus contorta* Dougl. ex Loud).

When planting, the most suitable density can be selected. This usually means adequate density to secure a good proportion of high quality sawlogs, but still open enough to limit the number of thinnings to two or three.

The type of seedlings has gradually been changed during the last three or four years. Two-year-old rooted seedlings are at present more commonly used than the four-year-old bare-root seedlings. These young, rooted seedlings are slightly cheaper to produce in nurseries, and they are much quicker and cheaper to plant in the field. Another advantage is that the planting season can be prolonged. However, as the young, rooted seedlings are smaller, scarification before planting is highly recommended and more necessary than when planting bigger four-year-old seedlings. However, I expect the gentlemen from Sweden and Finland to deal more closely with these problems.

THE IMPORTANCE OF RAW HUMUS ACCUMULATION IN BOREAL FOREST MANAGEMENT

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INTRODUCTION

Boreal forests are associated with accumulations of partially decomposed organic matter on the soil surface referred to as raw or mor humus.

Besides representing an important store of nutrients whose availability is largely controlled by microbial activity, this layer has thermal insulating properties and often has undesirable seedbed properties (Kraus, Weetman and Arp, 1978). Attempts in North America to develop biologically meaningful classifications of the humus layer have not been very successful. Classifications based on physical properties and appearance do not reflect the very complex biological properties of the layer. Chemical degradation into humic factions have also been difficult to interpret.

The use of designated forest site types have been more meaningful, using lesser vegetation to characterize a biological condition, which will respond to change in a consistent pattern. Each designated type has associated with it a humus layer of characteristic properties such as depth, texture, cation interchange capacity, N content, etc. Such classifications are now widely used in Canada to characterize the biotic or changing component of the site, as opposed to the physiographic or constant component of site expressed in landform and soil classifications (Linteau 1955, Lafond 1969). Some of the better known types, which cover very large areas of the boreal forest are the Black Spruce-Feather Moss Type; the Jack Pine-Lichen-Bearberry Type; and the Black Spruce Labrador Tea Type (Kabzems et al. 1976).

For each of these types there are characteristic patterns of succession following disturbance and recommended silvicultural practices. These patterns and practices are largely dependent on the properties of the humus layers of each site type. This paper will review some of these properties and point out some of the implications for silviculture practice.

NUTRIENT CONTENT AND AVAILABILITY

Rowell (1935) pointed out long ago that differences in mull and mor are not associated with different rates of organic matter decomposition, but as different types of decomposition. The accumulation of leaves, branches and roots represents, for many drier and shallow sites, the bulk of the macronutrient supply on the site. The richest boreal sites are associated with herbaceous vegetation, poorer sites with feather mosses, and ericaceous vegetation, and the poorest with lichens, if dry, and sphagnum, if wet. The presence of raw humus in itself has been suggested as characteristic of a very strong biological competition for nitrogen, associated with: high C/N ratios; a blockage of the N cycle; decomposition primarily accomplished by fungi; low concentrations of NH_4-N; little nitrification and large organic-N reserves. Except on some of the richest herbaceous sites, or those with seepage water, most forest ecosystems can be expected to be responsive to N fertilizer additions once the biological competition for N is expressed by closed crown canopies. Due to large P and K reserves in the humus layer, these elements are unlikely to be limiting, particularly on minerologically rich tills.

Following cutting or fire there is a period of much greater nutrient availability, which has been referred to as the "assart effect" by Rommell and Tamm (Tamm and Pettersson 1969). The magnitude and length of the assart effect are of great practical importance. They are associated with both the increased temperature and moisture which favors humus decomposition and the sudden lack of nutrient uptake and sudden availability for decomposition of large quantities of fine roots. While everybody recognizes this effect, little information is available on the rate and quantities of increased nutrient availability. In practical terms it is important to "capture" this nutrient availability in the desirable tree or shrub species.

It seems likely that in boreal forests lack of "nutrient sinks" would lend to spectacular NO_3-N losses noted in the bromocil treated watershed of Hubbard Brook, N.H., since presumably nitrification rates in mors is lower than the more moder type humus layers in New Hampshire. Of more concern on poorer sites with a natural component of *Ledium, Kalmia* and *Vaccinium* species, is to avoid "heathland degeneration"—the complete capture of the site by ericaceous species. Under these conditions, Damman (1971) has shown that a new type of humus layer, dominated by ericaceous roots develops, which represents a great immobolization of nutrients and is a stable climax type. Extensive areas of Newfoundland, Quebec and parts of Europe have developed heaths, particularly following repeated fires or grazing, which destroys forest regeneration.

In many older boreal forests there are often appreciable quantities of black spruce (*Picea mariana* [Mill.] B.S.P.) advance growth. Following mechanical harvesting, particularly on ericaceous type sites, the future productivity of patchy advance growth, in competition with *Kalmia* and *Ledium*, may be in question. On the poorest sites, particularly in jack pine (*Pinus banksiana* Lamb.), it could be considered as being "off-site" and should be removed. We should know more about the assart effect and advance growth potential.

Recognition of the assart effect is important in securing the reproduction. Prompt planting is required, following fires and cutting. For a nutrient demanding species such as white spruce (*Picea glauca* [Moench] Voss), this is particularly important if extended periods of "check" are to be avoided. For black spruce, prompt capture of the site by planted stock, which partially emulates the prompt natural regeneration following fire, can produce spectacular growth rates associated with high levels of available nitrogen particularly if other hardwood competition is removed by herbicides. Opportunistic species such as aspen (*Populus tremuloides* Michx.) exploit this natural condition, act as "scar tissue" in healing massive disturbances, and by rapid re-establishment of litterfall, play an important role in humus and nutrient conservation on dry and shallow sites.

Full tree logging, which removes large quantities of nutrients in foliage and removes potentially decomposable organic matter, thus has a double influence of reducing the length and magnitude of the assart effect and may also reduce the priming effect on decomposition of the slash. Our recent attempts (Weetman, Clemmer and Algar, 1979) to determine the magnitude of the direct export and to simulate with a humus process model, the effects of full tree logging, suggest the combined effects may be serious and involve N, P and Ca.

There are also some concerns about acid rain and heavy metal pollution problems which have been prevalent in Europe and around Sudbury, Ontario. European ecosystem studies of the SWECON project in Sweden, SOLLING project in Germany and the Spruce Ecosystem Study in Czechoslovakia are multidisciplinary projects designed to analyze these problems. We have no equivalent studies in the boreal forests of Canada.

SEEDBED AND THERMAL PROPERTIES

The literature on boreal forests is replete with references to the desirable properties of mineral soil and rotten wood, as opposed to raw humus, as seedbeds for spruce and pine, due primarily to problems of dessication. Of great concern here is the parallelism of the effects of forest fires and the effects of modern mechanized logging in creating suitable seedbeds on raw humus. The differences are dramatic and serious. Logging generally does not expose a sufficient amount, nature and distribution of mineral soil to adequately provide for appropriate seedbeds for conifers. Furthermore, except in some jack and lodgepole pine (*Pinus contorta* Doug. ex. Loud) stands, serotinous seed supplies are not available. Lack of utilization of aspen and birch (*Betula* spp.), leads to hardwood invasion and forest cover type switches occur. A study we conducted between 1966 and 1976 on 36 case history areas across Eastern Canada, in which we examined stands before, immediately after, and 5 and 10 years after logging, suggests (based on computer simulation of projected yields) a rather pessimistic picture (Frisque, Weetman and Clemmer, 1978).

Of concern are the vast areas logged each year. Of the approximately one million hectares (2.5 million acres) logged in Canada, about 600,000 ha (1.5 million acres) are in boreal forests. The lack of regeneration on these areas is of national concern and alarm for Canada. Besides the lack of money and nursery stock to plant areas, it is often biologically and physically infeasible to plant remote and rough areas on which it is difficult to physically prepare the site by heavy equipment in preparation for hand planting. The problem is confounded by low stumpage rates on Crown lands (which represent 95% of Canada's forests), public apathy and lack of labor. More amenable to solution, but still lacking much attention, are the technical problems of scarification to produce good seedbeds in thick humus. There has been a proliferation of locally developed and imported types of dragged and pushed equipment either designed to mix the humus and mineral soil or to push the humus aside.

Of concern here are the requirements to maximize heat penetration on humus insulated cold soils in boreal forests, where low temperatures limit both root growth and nitrogen availability, and to avoid excessive mineral soil exposure associated with flooding, frost heaving and lack of nutrients. Our approaches are largely empirical, based largely on availability of equipment. It ought to be possible to provide for a happy combination of seedbed properties and assart effects more often than we do. Perhaps more important is that, when we achieve a biologically desirable effect, we often cannot explain it.

Finally, we are now involved in pre-commercial thinning programs to space young stands with the aim of reduction of rotation ages, improved control of species composition and tree size. Scandinavian studies have shown organic matter decomposition to be closely temperature regulated and have shown positive effects of such treatments in greatly increasing absolute volume growth as compared to very dense untreated stands. The effects being largely attributed to greater forest floor snow depth, less forest penetration and, thus, improved humus thermal regimes and decomposition rates. Under biologically N stressed conditions, the application of both precommercial thinning and nitrogen fertilization may have synergistic effects. We need more factoral thinning and fertilizer trials in boreal forests to test these effects.

SUMMARY

Boreal forests are associated with raw humus conditions. An understanding of the physical properties, seedbed characteristics and nutrient storage and availability characteristics of this layer are essential to an understanding of both

the natural stand dynamics and the management problems of boreal forests. This knowledge is best assembled and applied within a forest site type classification which recognizes the biologically discrete associated tree, plant, soil and humus conditions. Our understanding of humus processes is often largely imported and is very incomplete. We need not only improve forest site classification, but much better analysis of organic matter decomposition processes and associated nutrient availability. Our work in this area is presently limited by available techniques and thinking which are more appropriate for the agronomic job of growing annual crops in mineral soils, rather than perennial forest crops, with closed nutrient cycles, on cold northern soils dominated by raw humus.

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NUTRIENT CYCLING IN INTERIOR ALASKA FLOOD PLAINS AND ITS RELATIONSHIP TO REGENERATION AND SUBSEQUENT FOREST DEVELOPMENT

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INTRODUCTION

The river flood plains of interior Alaska are the sites of our most productive forests. During the early development of interior Alaska these flood plain forests were heavily utilized for logs and lumber for construction and for fuel for powering river steamboats and heating homes. In the future, relatively fast growing balsam poplar (*Populus balsamifera* L.) and white spruce (*Picea glauca* [Moench.] Voss) forests will undoubtedly receive considerable utilization by the forest industry. These sites may also provide interior Alaska's best potential for future short rotation energy forests (plantations).

In order to best manage these forests it is essential that we have a thorough understanding of the ecological controls that are acting on these ecosystems throughout the entire successional sequence. The river flood plains also offer a unique opportunity to examine the course of forest ecosystem development and to gain insight into mechanisms which control this development. The various stages in primary succession reflect physical, chemical and biological controls of ecosystem structure and function. The interaction, or feedback relations, among the controls and ecosystem processes are displayed in occurrence of the respective vegetation types, their growth rates and longevity. Each successional stage has a species combination which is in harmony with site quality.

Understanding the interplay of controls over successional change is an important step to developing sound forest management strategies. For example, short circuiting succession by planting a late successional species, such as white spruce, on an early successional surface may result in markedly reduced growth rates because of nitrogen limitation. Unless substantial amounts of fertilizer can be applied it is necessary to take advantage of early successional alder and its site ameliorating additions of nitrogen to insure successful growth of spruce.

Another important feature of flood plains is the fact that many site factors which control ecosystem development are relatively constant. This condition enables a clearer picture to be obtained of the changes in system structure and function during the course of succession. For example, topography essentially is flat so that initially, runoff, drainage, etc. would be approximately the same at all sites. Level topography also results in relatively uniform initial microclimatic conditions. Soil parent material may also be quite uniform in chemical composition because of river mixing. As a result of these conditions the physical, chemical and biological controls of forest ecosystem development are more clearly defined and easily understood on river flood plains than in upland areas.

The Tanana River flood plain near Fairbanks offers an ideal opportunity to examine this primary succession in interior Alaska. The Tanana River is an actively meandering river fed primarily from glaciers in the Alaska Range and from unglaciated watersheds in the Tanana-Yukon uplands. Flood periods tend to occur during the spring snowmelt and breakup and during mid- to late-summer when rain or warm air interacts to quickly bring mountain streams to flood capacity. The spring flood can be short termed, caused by brief damming of the water by ice jams or it can be of a longer duration when exceptionally heavy snowpacks are melted by warm spring weather.

The area of this study lies within and adjacent to the Bonanza Creek Experimental Forest about 40-48 km (25-30 miles) southwest of Fairbanks. Here, on a number of islands and terraces adjacent to the river, all stages of forest succession can conveniently be observed. Over the past 15 years we have established a number of permanent plots in stands of most stages of succession where we have been recording vegetation changes, soils, and ecosystem processes, especially those related to nutrient cycling and biomass production. The data in figures and the following discussion are the result of these long term observations and is our preliminary attempt to synthesize this material in a discussion of flood plain succession. Some information from these studies has previously been published (Ganns, 1977; Van Cleve, 1973; Van Cleve and Viereck, 1972; Gill, 1971; Van Cleve et al., 1971; Viereck, 1970; Zasada and Gregory, 1969). The objective of this paper is to examine some controls of flood plain succession within the framework of nutrient cycling and system productivity and to examine how changes in the controls relate to regeneration and subsequent forest development.

EARLY SUCCESSIONAL STAGES ON THE TANANA RIVER

We define early successional stages as those which exist from the initial bare surface stage (I) through the open shrub stage (VI). These stages generally reflect dominance of physical-chemical control of successional processes with Stage III representing a transition stage.

Certain forms of physical control of ecosystem state and function generally are superimposed over the entire successional sequence. For example, terrace elevation above river stage reflects terrace age and determines frequence of flooding. However, the meandering nature of the river ultimately controls the fate of each terrace regardless of age. Thus older terraces at higher elevation may gradually be eroded along one reach with sediment deposited along another section of river channel initiating a new, low-level terrace. The higher elevation of old terraces and the advanced stage of forest development indicate these stages of succession are being influenced by alluvial erosion and deposition to a relatively small degree compared to lower elevation, younger terraces.

Until sufficient alluvium has accumulated to raise river terraces above the zone of frequent intra-year flooding, physical and chemical control (Stage I, Figure 1) dominate ecosystem structure and function. These mineral soil surfaces may appear to be ideal locations for seed germination and establishment. However, frequent inundation, sediment deposition and erosion makes them highly unstable zones for plant establishement.

During periods of dispersal abundant seed of herbs, shrubs and trees are deposited and germinate on these sites, but the shallow rooted seedlings will be washed away or completely buried during the next stage of high water. Nutrient cycling in this environment is largely controlled by saturated flow of soil moisture and leaching of nutrients with elemental concentrations similar to those encountered in river water.

A combination of physical and chemical control exists in the next stage (Stage II) which is characterized by the formation of a salt crust on the bare surface. At this elevation above the river less frequent intra-season flooding occurs. Flooding generally is restricted to spring break-up and during mid- to late-summer high water. Physical removal or burial of shallow rooted seedlings still might occur. Ground-water rises to the surface by capillary action and as a result of surface evaporation deposits substantial concentrations of salts, especially $CaSO_4$, or gypsum, and various chloride and carbonate bearing salts. The salt accumulation in the surface few centimeters of soil results in conductivities of nearly 12 mmhos/cm^2 in saturation extracts and SO_4 concentrations of 10 to 15,000 ppm of soil. The salts form a crust several millimeters thick largely composed of gypsum crystals mixed with soil particles. This high salt concentration may control germination and establishment of quaking aspen (*Populus tremuloides* Michx.) on the Tanana River flood plain. This important upland forest type is not encountered in the primary successional sequence on the flood plain although an abundant seed source is available in the adjacent uplands. Laboratory observation of germination success on samples of the salt crust indicate that aspen seed germination may be reduced by as much as 80% on crusts collected from terraces representative of the bare surface-salt crust and open shrub stages (Stages II and III, Figure 2). Balsam poplar (*Populus balsamifera* L.), the most important hardwood species on the flood plain sites, also show reduction in germination success in response to high salt concentrations, but to a smaller degree than aspen. Whether the effect is one of moisture stress, toxic salt concentrations or both is yet to be determined. Aspen seedlings germinated on salt crusts show substantially reduced rate of growth and smaller cotyledons and hypocotyls. This condition may result in reduced ability of seedlings to obtain sufficient

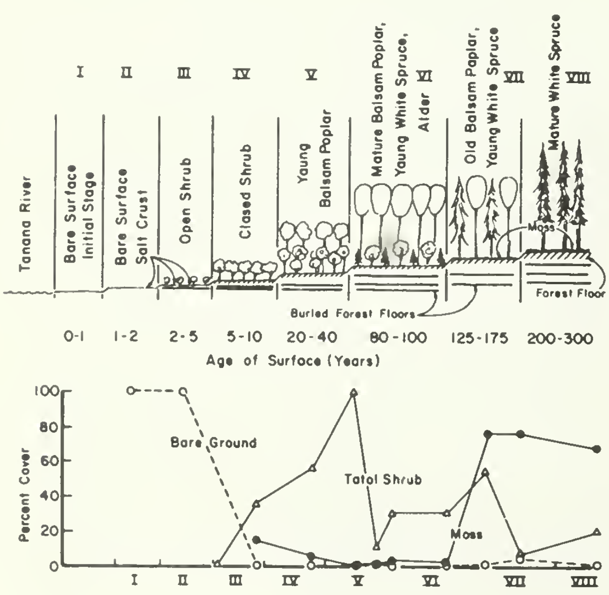

Figure 1—Estimates of percent cover for bare ground, total shrubs and moss on Tanana River successional sequence.

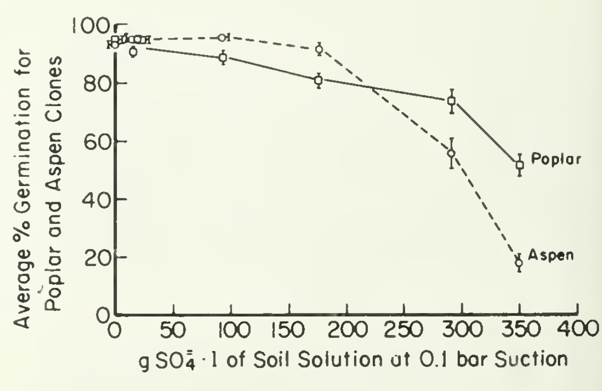

Figure 2—Average germination percentage for clones of balsam poplar and quaking aspen in relation to $SO_4^=$ concentration in soil solution.

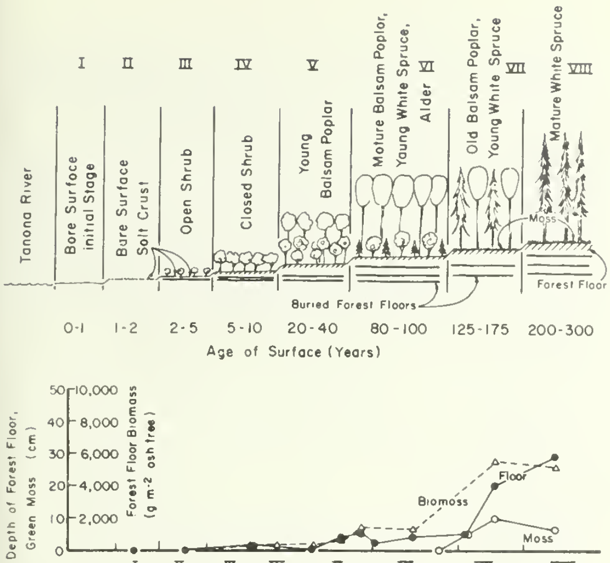

Figure 3—Forest floor and green moss depth and forest floor biomass on Tanana River successional sequence.

water to prevent dessication. Through Stage II, physical-chemical controls associated with alkalai soil formation dominate nutrient cycling.

Continued sediment deposition raises terrace surfaces to levels at which greater success obtains in seedling establishment and an open shrub stage of willow and alder results (Stage III, Figure 1). In addition, the continually changing river course results in quiescent periods during which newly established seedlings are not washed out by river erosion. Capillary rise of ground water continues. The visible manifestation of this phenomenon in the form of evaporate accumulation also occurs until terrace surfaces are higher than a meter above river stage. Even at this point high river stage may result in surface evaporation of ground water. However, leaching by snowmelt and rain water results in generally lower salt concentrations than encountered in late Stage II.

Stage III represents a transition between declining physical control and the rise of biological control of succession and nutrient cycling. Once well established, willows and alder act to slow river flow, stabilize terrace surfaces and provide biological control. By the end of this period, which ranges from 2 to 5 years, the impact of biological activity clearly is evident on ecosystem structure and function. Willow and alder (primarily *Alnus tenuifolia* Nutt. and a number of *Salix* spp. but with *S. alaxensis* [Anduss.] Cov. being the most abundant) shrub cover may reach nearly 40% and exposed mineral soil nearly disappears because of the development of a forest floor (Figures 1 and 3). Depth of forest floor ranges from 0 to 2 cm (0 to .8 in) and its weight approaches several hundred grams per square meter (Figure 3). Annual litterfall also approaches this magnitude (Figure 4). Accumulated above-ground live biomass is approximately 1 kg/m^2 (.21 lbs/ft^2) and annual net production aboveground is approximately 200 g/m^2 (.04 lbs/ft^2) (Figure 4). The increasing influence of biological control is also evident in the increase of amounts of soil nitrogen over earlier, non-vegetated stages (I and II). Soil nitrogen reserves may increase up to 4 times over that encountered in earlier stages (Figures 5, 6 and 7). This phenome-

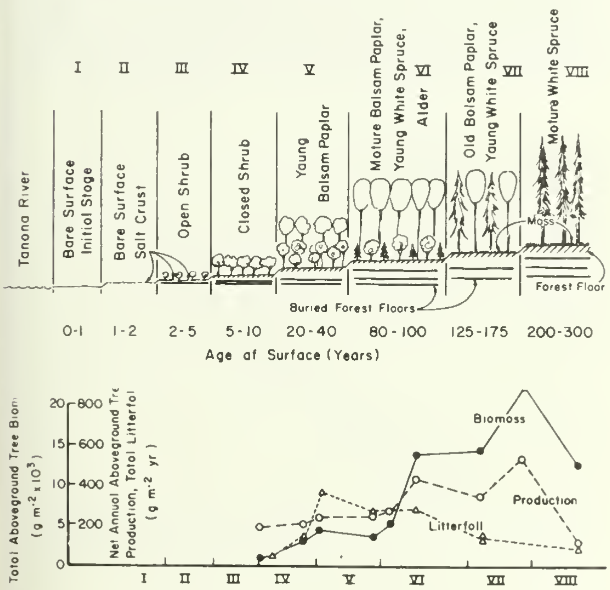

Figure 4—Forest productivity indices on Tanana River successional sequence.

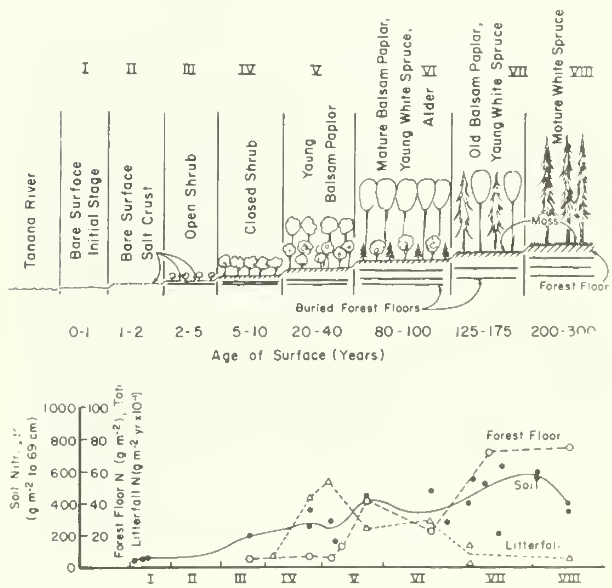

Figure 5—Indices of ecosystem nitrogen dynamics on Tanana River successional sequence.

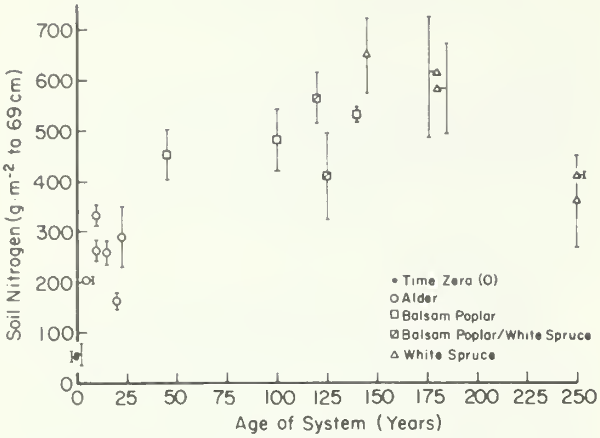

Figure 6—Trend of soil nitrogen reserves with time on the Tanana River floodplain.

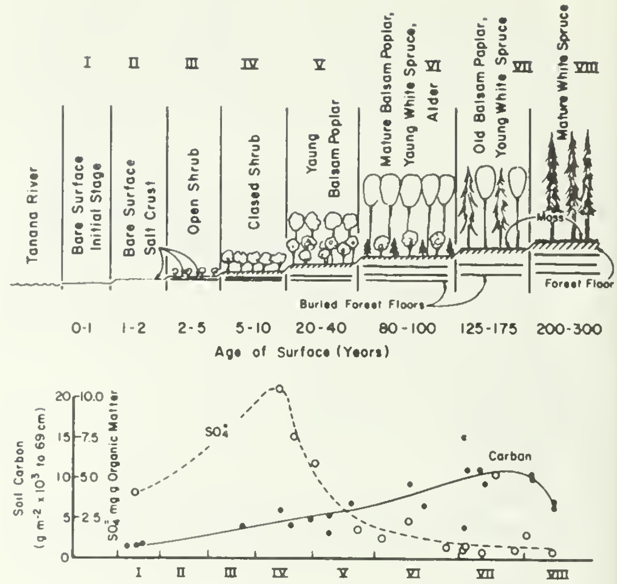

Figure 7—Change in soil carbon and sulfate content with time on the Tanana River floodplain.

non reflects the action of one of the most important site amelioration processes on the flood plain, symbiotic nitrogen fixation associated with *Alnus*. The presence of plant cover insures recycling of N through accumulation of this nutrient element in plant biomass and return to the soil in litterfall and root death. In the open shrub stage, annual return of N in litterfall is high (5 to 6 g/m^2) (.0010-.0012 lbs/ft^2) even though it may amount to less than 25% of the nitrogen stored in the forest floor. Another important control on nutrient cycling which appears at this time is the cation exchange capacity resident in the forest floor. Across a range of vegetation types from young to mature in upland and flood plain locations, for each gram increase in forest floor biomass the cation retaining power of the forest floor increases by 1.6 times (Figure 8).

The development of plant cover and the forest floor layer results in a decline in the importance of capillarity as a control of nutrient cycling and the virtual cessation of surface evaporation. Plants begin transpiring soil water, largely reducing the importance of capillarity in vertical transport of soil solution. The forest floor provides an effective barrier against evaporation at the mineral soil surface. Acidic leachates from the forest floor help to reduce surface soil pH and promote leaching of salts from the surface soil layers. However, it appears that time intervals of up to 300 years may be necessary before the concentration of sulfate and other minerals declines to lower, more stable levels (Figure 7). From the open shrub stage on, nutrients are concentrated in biological tissue largely through expenditures of energy fixed by photosynthesis and released for recycling by energy expended in microbial respiration.

MID-SUCCESSIONAL STAGES ON THE TANANA RIVER

We define mid-succession to extend from the closed shrub stage (IV) through the mature balsam poplar stage (IV), a period of approximately 75 to 90 years. This period is characterized by a rapid increase in shrub cover and net productivity of balsam poplar (Figures 1 and 4). Tree basal areas may reach 35 m^2/ha (153 ft^2/acre), or 75% of the maximum basal area reached during the mature stages (Figure 9). Net annual production of balsam poplar, standing crop tree biomass and trce basal area appear to reach a peak for this vegetation type in mature balsam poplar stands (Stage VI). As the balsam poplar canopy closes the shrub layer changes drastically. A number of pioneer willows are intolerant of the shade and disappear completely. *Salix alaxensis* and *Alnus tenuifolia* persist but begin to decline in vigor and abundance. Other more shade tolerant

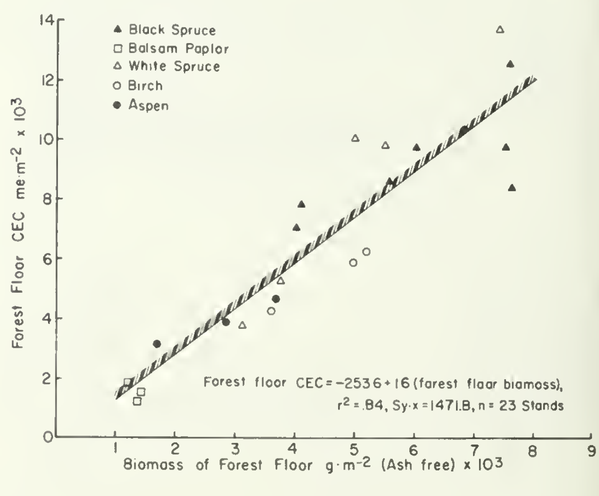

Figure 8—Cation exchange capacity in relation to biomass of the forest floor for interior Alaska forest types.

shrubs such as rose (*Rosa acicularis* Lindl.) and highbush cranberry (*Viburnum edule* [Michx.] Raf.) become common but do not have a high cover percentage. By the end of the young balsam poplar stage, shrub cover has markedly declined from near 100% to about 10% because of overstory shading. However, later in the balsam poplar stage during the period from about 80 to 100 years, the crown canopy has opened and shrub cover has increased to nearly 30%. The forest floor in mature balsam poplar stands attains about 1/6 of the total depth and biomass encountered on higher terraces supporting mature white spruce at 300 years (Figure 3). Standing crop of tree biomass may reach 15 kg/m^2 (3 lbs/ft^2) and net annual above ground production 440 g/m^2 (.09 lbs/ft^2), or 80% of that encountered in mature white spruce (Figure 4). Litterfall declines from a peak of 350 g/m^2 (.07 lbs/ft^2) early in Stage V to 250 g/m^2 (.05 lbs/ft^2) in Stage VI (Figure 4). This decrease in litterfall probably reflects the effect of higher stand density (1500-2000 stems/ha [600-800 stems/acre]) and intense competition for resources in the young balsam poplar stands (Stage V). Nearly 20% of the litterfall at the peak of deposition is woody plant debris, reflecting the intense natural thinning experienced by these young stands during this period compared with 10 to 14% of woody litter in the mature balsam poplar stage.

During this period mineral soil nitrogen reserves increase from about 300 g/m^2 (.06 lbs/ft^2) to 500 g/m^2 (.10 lbs/ft^2), near the average maximum encountered on the flood plain (Figures 4 and 5). This reflects the continued impact of biological nitrogen fixation associated with alder. However, in the mature balsam poplar stage the forest floor contains only about 50 g N/m^2 (.01 lbs N/ft^2). As a result of the decline in litterfall, annual return of N to the forest floor has decreased from a peak of nearly 6 g/m^2 (.0012 lbs/ft^2) to 3 g/m^2 (.0006 lbs/ft^2). Toward the end of the mature balsam poplar stage (VI) soil carbon content increases to between 9 and 10 kg/m^2 (1.8 and 2.1 lbs/ft^2), while profile SO_4 concentration declines to approximately 1 mg/g organic matter (.001 oz/oz) (Figure 7).

Physical and chemical controls still play a declining but important role in productivity and nutrient cycling through mid-succession. For example, capillarity may supply ground water to the tree rooting zone so that vegetation has adequate supplies of water throughout the growing season even during droughty periods. In addition, even though the soil solution appears to be low in such important nutrients as nitrogen and phosphorus, slow movement of soil solution through the rooting zone, along the gradient of the river may result in continual replacement of these reserves and satisfy plant nutritional demands. Leaching of surface soil layers by more acidic solutions moving through the forest floor results in the decline of soil pH from 7 or above to slightly acid range. This undoubtedly improves the availability to plants of phosphorus, which, under neutral to alkaline soil reactions and in the presence of abundant calcium, would largely be insoluble.

Flooding and sedimentation, now occurring at less frequent intervals, continue to increase terrace elevations. Buried forest floors, which are incorporated into the soil by periodic sediment deposition, are zones of low density, high water retaining capacity and high nutrient concentration. This environment favors abundant microbial activity and organic matter mineralization. Plant roots are markedly concentrated in these buried organic layers.

Up to this point in succession, the plant species which have been most successful in establishing themselves are broad-leaved, deciduous species (willows, alder, balsam poplar). Most of these species easily regenerate either by seed or by stump or root sprouting. They are also generally shade intolerant and have astonishingly rapid growth rates during early stages of stand development. These growth strategies appear to insure their quick establishment during stages of succession when ground surfaces are least stable and subjected either to erosion or periodic sedimentation.

Only after terrace elevation has reached the point where sediment deposition has declined to a relatively infrequent occurrence or the river course has markedly shifted to result in a quiescent period with regard to sedimentation, can white spruce become successfully established. White spruce requires a mineral soil seedbed (Zasada and Gregory, 1969) for germination and establishment. However, with perennial foliage it does not appear able to survive repeated within year, or yearly sediment deposition on needle surfaces. Seedling top growth rates are not rapid enough to elevate foliage to a level at which needles would be free of siltation. In addition, root growth rates may also be slow. In combination with lack of sprouting capability, these factors may further limit the ability of spruce seedlings to withstand erosion, overcome potential oxygen limitation to root systems following sediment deposition, or seek adequate water supply. Periods of drought and/or low water and deficient moisture supply by capillarity may also decrease seedling survival.

By the time of poplar stand maturity, the physical site conditions have been favorable for a sufficient time interval for spruce to become well established in the understory (Stage VI). During the late intermediate and early mature successional stages white spruce becomes a dominant species. Through the intermediate stages of succession tree growth and nutrient cycling have been dominated by relatively energy- and nutrient-costly growth strategies. For example, one gram of nitrogen (.03 oz) must be taken up by balsam poplar in the production of 50 grams (1.6 oz) of new foliage. However, 100 grams (3.2 oz) of white spruce foliage are produced per gram of nitrogen (.03 oz) taken up. One gram (.03 oz) of balsam poplar foliage supports the production of one gram (.03 oz) of branch and trunk wood. In white spruce one gram (.03 oz) of current foliage supports the production of two grams (.06 oz) of branch and trunk wood. Poplar must replace its entire complement of leaves each year, an energy costly strategy. On the other hand white spruce may replace only 10 to 12 percent of its foliage with new material each year and leaf longevity may extend to 7 years or more.

In summary, transition from mid- to late-successional forest stages is marked by the change from shorter term, rapid growth, energy and nutrient extravagant ecosystems to longer term, sustained growth in forests that appear to be energy and nutrient conservative in their growth pro-

cesses. The transition is also marked by the appearance of moss as a dominant component of the ground surface vegetation layer. These non-vascular plants are effective competitors with vascular plants, including trees, for mineral nutrient reserves.

MATURE SUCCESSIONAL STAGES ON THE TANANA RIVER

We define mature successional stages to be those which have the dominant tree basal area composed of white spruce. The young white spruce-old balsam poplar stage (VII) continues to have old balsam poplar as an overstory component but these individuals comprise less than 10 m^2/ha (44 ft^2/acre) basal area compared with the near 50 m^2/ha (218 ft^2/acre) basal area contributed by white spruce (Figure 9). Late mature stages (Stage VIII) have little or no balsam poplar remaining and white spruce basal area ranging between 40 and 50 m^2/ha (174 and 218 ft^2/acre). During the mature successional stages, shrub cover declines from a peak of about 50% in Stage VII to between 10 and 20% in Stage VIII (Figure 1) although there is a slight increase with age as the mature spruce stands become more open. One of the most dramatic changes to take place in the white spruce stages is the development of the moss mat. As the spruce canopy closes the feathermoss, *Hylocomium splendens* (Hedw.) BSG and *Pleurozium schreberi* (Brid.) Mitt., become dominant on the forest floor and the moss cover reaches nearly 80%. Bare ground surface again appears (up to 5%) as mature poplar and spruce fall and heaving of root systems exposes mineral soil. Some spruce seedling regeneration may arise on soil mounds.

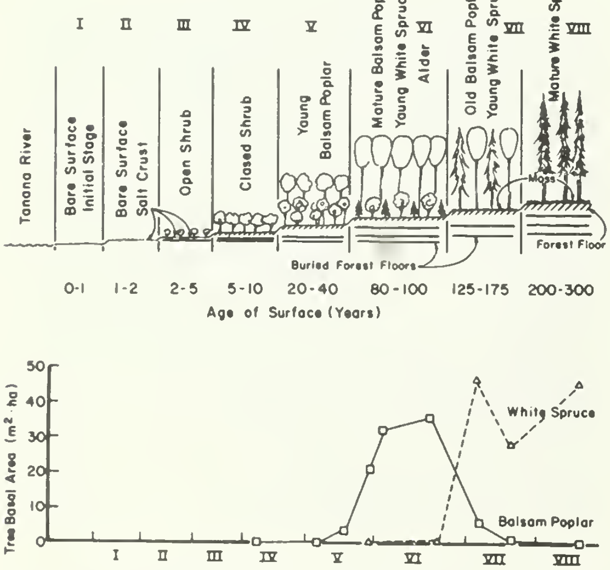

Figure 9—Tree basal area on the Tanana River successional sequence.

Depth of forest floor (25 to 30 cm [10 to 12 in]) and forest floor biomass (5000 g/m^2 [1.02 lbs/ft^2]) reach maximum values in mature white spruce stands (Figure 3). Depth of living moss tissue may add an additional 10 cm (4 in) to total forest floor thickness, providing an effective insulating mat and maintaining cool soil temperatures compared with earlier stages of succession.

Accumulated aboveground tree biomass in the white spruce may reach 22 kg/m^2 (4.5 lbs/ft^2) at approximately 180 years (Stage VII) but this total probably declines to a lower level in over-mature forests. The peak of net annual production, 500 g/m^2 (.10 lbs/ft^2) is attained by 200 years and again probably declines when the stand reaches over-maturity. Total annual litterfall declines from approximately 180 g/m^2 (.04 lbs/ft^2) to less than 100 g/m^2 (.02 lbs/ft^2) from early to late mature white spruce stages.

Soil nitrogen continues to increase from the levels of the balsam poplar stages (V and VI) and reaches an average maximum of nearly 600 g/m^2 (.12 lbs/ft^2) early in the mature stage and declines to slightly less than 400 g/m^2 (.08 lbs/ft^2) in late mature stages (Figures 5 and 6). We feel this change in soil nitrogen reserves is caused by continued removal by plant growth and accumulation in standing live and dead biomass and in the forest floor. Verification of this trend awaits estimation of productivity and nutrient relations in very old white spruce forests. Forest floor nitrogen content remains constant at the peak value of approximately 80 g/m^2 (.02 lbs/ft^2). Nitrogen return to the forest floor in litterfall approaches a lower value of about .7 g/m^2/yr. (.00014 lbs/ft^2/yr.). The turnover time for N in the forest floor at this stage is slow, approximately 125 years.

Along with soil nitrogen, carbon content reaches a maximum level of nearly 10 kg/m^2 (2.1 lbs/ft^2) in Stage VII but decreases in Stage VIII to about 7 kg/m^2 (1.4 lbs/ft^2) (Figure 7). At the present time it is difficult to attribute the control of decline ana amounts of carbon and nitrogen to shifts in biological processes or variability in conditions on the river terrace. As might be expected, sulfate reaches the lowest concentration levels of the successional sequence, .6 mg/g of organic matter (.0006 oz/oz). Surface mineral soil horizon pH approaches 5, reflecting continued leaching of Ca, Mg, K. In addition, the forest floor has developed to nearly the maximum degree its retaining capacity for cations (Figure 8). Forest floor biomass of 5 kg/m^2 (1 lb/ft^2) will have a cation exchange capacity of 7 to 8 eq/m^2 (.65 to .74 eq/ft^2). This capacity is nearly 80 times greater than the total equivalents of cations (.09 eq/m^2 [.008 eq/ft^2] Ca + K + Mg) returned in litterfall in one year on a mature stage forest site.

At this point in succession, capillarity and sedimentation are no longer functioning as controls of primary production and nutrient cycling. Mature stage terrace levels are sufficiently high above the river level that near castastrophic flooding is required for substantial sedimentation to occur. Leaching of surface soil layers depends on downward movement of snowmelt water and precipitation through the acidic forest floor.

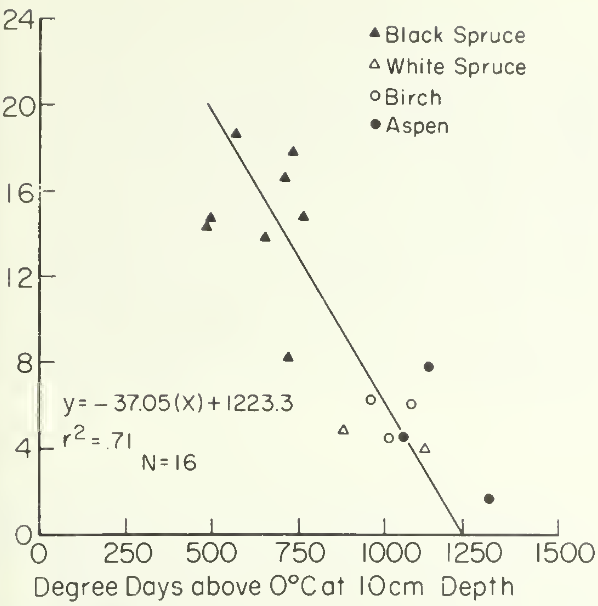

Figure 10—Forest floor depth-temperature relationship for interior Alaskan forest types.

Some wind deposition of sediment occurs in all stages of succession when silt particles are picked up from the mineral surfaces of Stages I and II. Amounts of nutritionally important elements deposited by this mechanism are not known at this time but patterns of loess movement on the floodplain appear to be highly variable. Given the requirement of bare mineral soil seedbeds, regeneration of succeeding forests depends on seedling establishment on windthrow mounds. However, the occurrence of this phenomenon is generally only sporadic. In any case, wind deposition of sediment appears insufficient to provide mineral soil seedbeds for spruce regeneration.

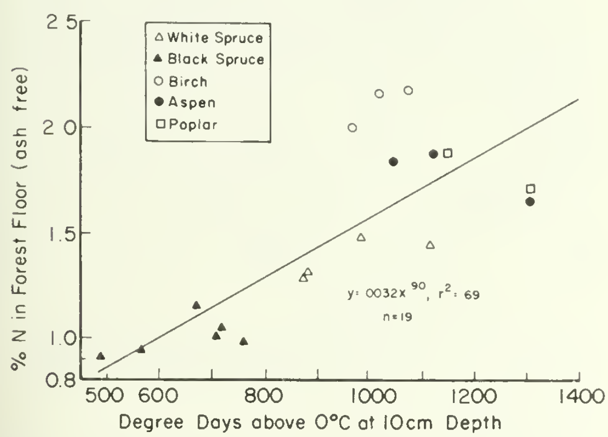

Figure 11—Forest floor nitrogen concentration in relation to temperature for selected interior Alaskan forest types.

With one exception, primary production and nutrient cycling processes at this stage reflect the dominance of biochemical control. As succession advances, the forest floor continues to increase in thickness and mass of stored organic matter. In late successional stages, moss contributes an additional layer of organic matter which has low thermal conductivity. Progressively increasing thickness of the forest floor is associated with decline in soil temperatures (Figure 10). We have followed the course of soil temperature at the 10 cm (4 in) depth for the period May 20 to September 10 in a wide range of mature vegetation types on upland and lowland sites. Heat sums calculated above 0°C show that for each one cm (.39 in) increase in forest floor thickness, the heat sum declines by approximately 37 degrees. The decline in soil temperature may cause slowed rates of soil organic matter decomposition and release of mineral elements important in plant nutrition. For example, across the range of upland and lowland forest sites, a fairly strong relationship exists between forest floor nitrogen concentration and soil heat sum (Figure 11). This trend reflects the higher nutritional status of broad-leaved deciduous vegetation type litter. It may also reflect more rapid microbially mediated soil nitrogen turnover on warm compared with cool sites, and larger amounts of N available for use by plants.

Although we have concluded this discussion with the mature white spruce stands the succession does continue on the older terraces. Regeneration of succeeding forests following the mature white spruce stage (VIII) is varied. In some cases these white spruce stands are replaced by black spruce. The mechanisms involved in this change are not thoroughly documented or understood but appear to be related to the formation of permafrost and colder waterlogged soils (Drury, 1956; Gill, 1971; Viereck, 1970). The role of fire on these flood plain forests is less than in upland sites because of the protection afforded by sloughs and river channels. However, fire does occasionally burn through flood plain white spruce stands and may be a factor in conversion to black spruce.

On some protected uplands white spruce stands are known to persist for at least 300 years. In these cases regeneration on windthrow mounds, old logs and other sites where the organic layer is disturbed may result in uneven-aged stands. Also, it is possible that the extreme flood may provide a mineral surface sufficient for the germination of either black or white spruce under the mature white spruce canopy.

FOREST MANAGEMENT IMPLICATIONS

Timber stands along the Tanana River have largely been an ignored resource in the recent past. In the early years of the twentieth century a small amount of harvesting took place for lumber, house logs and riverboat fuel. Since that time, however, there has been almost no activity in timber harvesting or stand management on these sites. In addition, very few silvicultural studies have been under-

taken on river bottom locations. Instead, the majority of tree regeneration and stand growth studies have been concentrated on upland sites adjacent to the Tanana River.

As we have pointed out, research along the Tanana River has concentrated on defining the successional stages and characterizing these stages with respect to structure, function, and controlling mechanisms. What has emerged is a fascinating picture of a highly dynamic system, constantly undergoing change and where major processes are really quite different from those operating on adjacent uplands. Thus, management strategies which are completely different from those employed on upland sites will almost certainly be necessary for the bottom lands.

What management options can we infer from what we already know about ecological relationships on interior Alaskan flood plains? First, and perhaps most important, management practices must conform with the dynamic nature of the ecosystem. In other words, forest land managers should design their treatments to conform to the successional sequences rather than trying to work at cross-purposes to succession. For example, it may very well prove impractical for the forest manager to harvest more than one rotation of balsam poplar from low terrace sites which are still subjected to rather frequent flooding (Stages V and VI). Perhaps continuous uplift by sediment deposition results in sites much better suited to the growth of white spruce and hardwoods other than balsam poplar.

Certain sites along major rivers may be ideally suited for energy plantations, where fast-growing high biomass production is the aim. However, these sites should be chosen carefully to insure maximum productivity. Based on what we have learned thus far about site productivity, it would appear that closed shrub and young balsam poplar sites (Stages IV and V) would be most appropriate for energy plantations.

Another factor which must be taken into account in designing forest management plans is the change in soil properties which occur during the succession sequence. Although balsam poplar would be the most appropriate hardwood to plant on early successional sites, it probably would not be the best suited species to plant after harvesting mature white spruce. In these high terrace locations capillarity no longer maintains consistently high levels of soil moisture; consequently these sites are drier during the growing season, requiring a more drought-tolerant tree species. Perhaps aspen would be a more successful hardwood on these high terrace sites.

As previously mentioned, land managers should be aware of the importance of alder in early succession in supplying soil nitrogen. Accordingly, any practice that precludes the development of alder on sound sediments would seriously jeopardize future soil nutrient supplies and the productive capacity of the site.

A question which arises with increasing frequency is how best to regenerate river terrace sites from which mature white spruce has been harvested. In view of the necessity of exposing bare mineral soil, some sort of site preparation will probably be a necessary step following logging. Perhaps this could best be attained by mechanical treatment or burning. Burning might have the added advantage of resulting in the release of at least a portion of the nutrients previously tied up on the forest floor. Species selection is also open to question and perhaps mixed species management should be the goal rather than re-establishing pure stands of white spruce. The mixture might contain hardwoods, such as aspen and paper birch, as well as white spruce. Such stands would be more similar to those occurring on upland sites and should have a favorable effect on soil nutrient levels.

ACKNOWLEDGMENTS

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REGENERATION PROBLEMS AND OPTIONS FOR WHITE SPRUCE ON RIVER FLOODPLAINS

IN THE YUKON TERRITORY

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INTRODUCTION

Currently the Yukon Territory represents the area of responsibility for research into forest lands north of 60° latitude at the Pacific Forest Research Centre.

The majority of forest operations for industrial wood production are located on the floodplains of the Liard River drainage system in the southeastern portion of the territory around Watson Lake (Figure 1). As white spruce

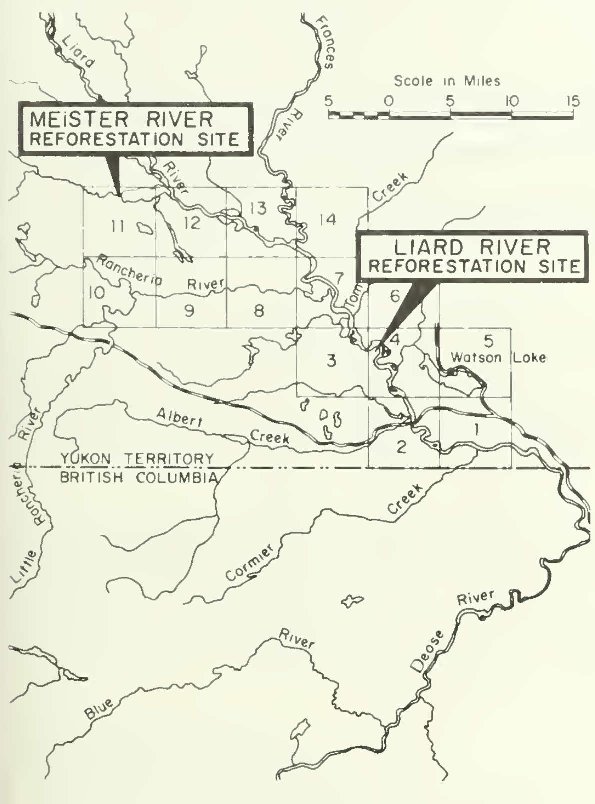

Figure 1.–Location of Pacific Forest Research Centre/ Yukon Lands and Forest Service Watson Lake Reforestation Trials, Liard River drainage system, Yukon Territory, Canada.

(*Picea glauca* [Moench] Voss.) represents the chief commercial species in the area, the majority of reforestation research at this time is centered on investigation of regeneration options for white spruce on these floodplain sites.

White spruce is one of the most interesting species in the boreal forest. Transcontinental in its distribution white spruce is capable of performing well over a wide range of soils and climatic conditions. It is shade tolerant in early life and able to establish and grow under a moderate brush or hardwood canopy. Seed supplies for natural regeneration are generally adequate despite being variable in abundance and of average viability when compared to such species as trembling aspen (*Populus tremuloides* Michx.). Genetic variability is thought to be great enough that considerable gains may be possible through tree improvement programs (Stiell, 1976; Zasada, 1969). Concurrently, this species offers a number of challenges to forest managers concerned with regenerating it on cutover, burned or other temporarily unproductive forest lands. If there are lands designated for reforestation by either natural or artificial seeding, then a carefully coordinated sequence of events must take place. Preferably an adequate amount of viable seed must fall onto a receptive seedbed of mixed mineral-organic soil which, in turn, is as free of vegetative competition as possible yet not so exposed that it becomes susceptible to severe drying and/or repeated frost heaving. If one of these general conditions is out of sequence then an entire reforestation program of this type may achieve less than desired results (Stiell, 1976; Zasada, 1972).

As a plantation species, white spruce requires conditions similar to those necessary for successional seeding. Young planted spruce are vulnerable to early or late frosts, low soil temperatures and rapid reinvasion of competitive vegetation, all or any of which can severely inhibit growth and development until the plants have become well established (Stiell, 1976).

The alluvial floodplain sites in the Yukon Territory, while rated as having the highest potential for growing trees of any area there (Oswald and Senyk, 1977), offer some difficult conditions to work with. They are characterized by a short growing season and cool soils yet they possess good fertility and thus are prone to reinvasion by balsam poplar (*Populus balsamifera* L.), willow (*Salix* spp. L.) and aspen. Periodic spring flooding of the flats, if heavy

and prolonged, may contribute to seedling mortality through drowning or burying the trees in a thick layer of silty debris.

In the fall of 1975 two research installations were established on the Liard and Meister Rivers (Figure 1) in cooperation with the Yukon Lands and Forest Service. The objectives of these trials were to determine the Yukon's regeneration needs, resolve the biological impediments to establishment of trees on the floodplain sites and to broaden fundamental silvicultural knowledge of these forest types.

DESCRIPTION OF THE STUDY AREAS

The Liard River site is located at 60° 08' N, 128° 58' W while the Meister River area is situated at 60° 20' N, 129° 35' W. The two areas fall within the B. 24 section of the boreal forest as described by Rowe (1972) and the Liard River ecoregion as classified by Oswald and Senyk (1977). The floodplains are at elevations of 180-200 m (591-656 ft) and lie within the subarctic climatic zone with a frost free growing period of about 60 days (Hirovonen 1968). Growing season temperatures average 15°C with annual precipitation in the range of 400 to 500 mm (16-20 in). The aspect is level.

The soils of the experimental areas were formed through successive alluvial depositions and are classified as moderately well drained and regosolic (Jeffery 1964). Generally they are rich in bases. However, analysis of soil samples from the Meister indicated a mildly acidic characteristic with an average pH of 6.5. The profile is made up of alternating layers of somewhat coarse-textured sandy loams, silt loams and loamy sands. What could be considered base materials were reached at 86+ cm (34 in) and consisted of gravelly sands and fine to coarse sands with a few rocks.

Data obtained on the Meister River revealed that originally there was a moderately dense stand of white spruce interspersed with willow and a few poplar. Analysis of the data determined stand averages of 23.1 cm (9.09 in) d.b.h., 19.3 m (63.3 ft) height and 64 years of age. Site class was rated at medium with a site index of 26 m (85 ft) at 50 years. Total basal area reached 56.7 m^2 (610.3 ft^2) with a merchantable basal area of 54.8 m^2 (589.9 ft^2) and a merchantable volume of 392.4 m^3 (13,855.6 ft^3). Both areas were clear-felled; the Meister in April 1974 and the Liard during February-April 1975.

METHODS

The two test sites were selected during the summer of 1975. The reforestation options selected for study included: planting, broadcast seeding, spot seeding and seeding from natural sources on scarified and unscarified ground conditions over two treatment periods; fall and spring. The first replication of the fall treatments was applied in September 1975 and the spring treatments in June 1976. The second replication was applied in the fall of 1976 and the spring of 1977. A total of seven research blocks were established at each of the sites and they were arranged in randomized complete block design with a split-plot (Arnott et al., 1979). A total of 12.84 ha (31.65 acres) were strip scarified with a Cat. D6C and a Komatsu D60A; both tractors utilized an angled dozer blade in 1975. In 1976 a brush blade was employed and found to be much more effective.

Seed for the trials was collected from two locations: 1) Haines Junction at 60° 45' N, 137° 30' W at an elevation of 619 m (2,030 ft) and 2) Watson Lake at 60° 06' N, 128° 50' W at an elevation of 701 m (2,300 ft). Cones were collected during August and September 1973 and extracted at the Provincial Tree Nursery in Oliver, Alberta (Arnott et al., 1979).

Plots assigned to the spot seeding treatments were hand seeded with an average of six seeds per spot. A Cyclone model 10 seeder was employed for the broadcast seeding at an application rate of 2.24 kg per ha (2 lbs/acre).

Seed from the sources indicated above was used to produce stock for the planting treatments. The seed was sown into BC/CFS Styroblock 2 containers during the spring of 1975 at PFRC, grown there, and transported to Watson Lake in July of that year where they were placed in a shadehouse. The fall treatments were planted in September and the remainder of the stock was overwintered on the ground in a woodlot adjacent to the shadehouse. In June and July of 1976, the spring planting treatments were applied using the overwintered stock. The entire process was repeated during 1976/77 with the fall treatments applied in September 1976 and the spring treatments in June of 1977. On the planted, scarified plots, three microsites were recognized: slope, hump and flat whereby the slope consisted of the side of the scarified trough, the hump was the mound of loose earth between the tracks of the bulldozer and flat areas were made up of the lightly compacted soils of the bulldozer tracks themselves.

The trials are to be assessed biennially for the first five years after establishment. For the planting trials assessment techniques developed at PFRC are used. Basically the sheet records the status of each seedling, any damage or injury it may have sustained, its microsite, shade conditions, total height plus a subjective assessment of its quality (Arnott et al., 1979).

The natural and broadcast seeding treatments are evaluated by selecting 50 half square-metre samples per line randomly allocated within the established subplots. The spot seeded subplots are sampled by randomly selecting 50 of the seeded spots from each subplot. The number of germinants and subsequent seedlings are tallied with height measurements recorded in the third year after establishment (Arnott et al., 1979).

This year, data collected on the plots established in 1976-77 completed the third year assessment of these reforestation trials. Although there is another assessment to be made in the fifth year after establishment data from the third year assessments were subjected to analysis of variance to determine the significance of trends which are becoming obvious in the mid-term of the study.

RESULTS

Tables 1 and 2 present the results of the third year assessment of the seeding and planting trials. Although the study is incomplete there are several significant trends which are worth consideration at this time.

Direct Seeding

1. Stocking. Direct seeding on unscarified ground has failed. Stocking levels ranged from a low of 4.6% for fall spot seeding to a high of 8.5% for fall broadcast seeding. When statistically compared to treatments applied on scarified ground all results were significant at the $P = 0.01$ level. As a result, no further comparisons were made between scarified and unscarified treatments which accounts for their absence on Table 1.

Direct seeding on scarified ground, although more successful than on unscarified ground, still should not be considered as the ultimate regeneration treatment. Stocking levels ranged from an unacceptable low of 28.8% for fall spot seeding to a moderately successful 66.5% for spring broadcast seeding. Statistically significant results were obtained from comparisons of the broadcast seeding treatment with the spot treatments regardless of the time of application (spring or fall). Spring broadcast seeding out performed natural seeding at both the $p = 0.05$ and $p = 0.01$ levels while fall broadcast seeding did not differ significantly from natural seeding at either level. Differences were not realized between natural seeding and either of the spot seeding treatments with regard to stocking.

Table 1: Means and significance for scarified treatments of seeding trials three years after establishment at the Liard and Meister Rivers, Yukon Territory.

	Treatment	Treatment Mean	0.05%	0.01%
% of samples with established seedlings (% stocking)	SFS	28.8	a	a
	SSS	33.4	a	ab
	SN	39.6	ab	ab
	SFB	52.2	bc	bc
	SSB	66.5	c	c
Mean number of established seedlings per stocked sample	SFS	2.05	a	a
	SSS	2.35	a	a
	SN	2.88	a	ab
	SFB	3.78	ab	ab
	SSB	5.68	b	b
Mean height of established seedings (cm)	SFS	3.59	a	a
	SSS	3.77	ab	a
	SN	4.11	ab	a
	SFB	4.38	ab	a
	SSB	4.56	b	a

Treatment codes:
- SFS—Scarified Fall Spot
- SSS—Scarified Spring Spot
- SN—Scarified Natural
- SFB—Scarified Fall Broadcast
- SSB—Scarified Spring Broadcast

NOTE: Numbers followed by similar letters are not significantly different at the indicated significance level: $p = 0.05\%$; $p = 0.01\%$.

Table 2: Percent survival and average height of seedlings three years after planting at Liard and Meister Rivers Yukon Territory

Treatment	Treatment Mean	0.05%	0.01%
	% SURVIVAL		
UF	84.2	a	a
SFF	85.9	ab	ab
SFS	88.3	ab	ab
SSS	88.7	ab	ab
SSF	88.7	ab	ab
US	88.8	ab	ab
SFH	89.7	ab	ab
SSH	92.6	b	b
	AVERAGE HEIGHT (cm)		
US	19.6	a	a
UF	21.4	ab	a
SSF	21.7	abc	ab
SSS	23.1	bc	abc
SFF	24.1	c	bc
SFS	26.1	d	c
SSH	26.3	d	c
SFH	26.7	d	c

Treatment Codes:
- US—Unscarified Spring
- UF—Unscarified Fall
- SFF—Scarified Fall Flat
- SSF—Scarified Spring Flat
- SFH—Scarified Fall Hump
- SSH—Scarified Spring Hump
- SFS—Scarified Fall Slope
- SSS—Scarified Spring Slope

NOTE: Numbers followed by similar letters are not significantly different at the indicated significance level: $p = 0.05\%$; $p = 0.01\%$.

2. Establishment of seedlings. Seedlings did not establish well on unscarified soil. Establishment in terms of seedlings per stocked sample ranged from a low of 0.64 for the spring broadcast treatment to a high of 1.10 for fall spot seeding. Again, all scarified treatments significantly out performed the unscarified treatments.

Comparisons on scarified ground produced few significant results. Spring broadcast seeding produced an average of 5.68 seedlings per stocked sample to better all other treatments except the fall broadcast seeding at the $p = 0.05$ level. Spring broadcast seeding differed only from the spring spot treatments ($p = 0.01$). No other differences were realized at either level.

3. Mean height. The unscarified plots produced seedlings with the greatest average height. Unscarified fall broadcast plots produced an average seedling height of 9.71 cm (3.82

in) followed by the unscarified natural plots at 7.68 cm (3.02 in). Unscarified fall and spring spot treatments produced the smallest seedlings at 2.65 cm (1.04 in) and 2.99 cm (1.18 in), respectively. Average height differed statistically only at the p = 0.05 level between scarified plots. Only one difference was obtained whereby spring broadcast seeding (4.65 cm; 1.83 in) out-performed spring spot seeding (3.59 cm; 1.41 in). Because of the poor results obtained from unscarified plots with regard to stocking levels and seedling establishment, statistical comparisons were not obtained among unscarified plots or between these and scarified plots at the time of computer analysis for any of the three performance parameters discussed here. Therefore it is not possible to state whether the large average heights obtained for the two unscarified treatments noted above are statistically significant.

Planting

1. Survival. Among all combinations of microsite and planting season on scarified or unscarified plots only one significant difference was determined. Trees planted on the hump microsite on scarified ground in the spring out performed trees planted in the fall on unscarified ground at both probability levels (p = 0.05 and p = 0.01). Survival rates for the two treatments were 92.6% and 84.2%, respectively.

2. Mean height. Unlike survival rates a large amount of variation has been observed with respect to height growth. Most of the highly significant variation is attributable to the main effects of scarification or the absence of it. Less significant variation occurs frequently among microsite treatments and very little occurs as a result of planting season.

Average treatment heights ranged from a low of 19.6 cm (7.72 in) for the unscarified spring planting to a high of 26.7 cm (10.51 in) for the fall planted seedlings on the hump of microsite. This reveals a difference of 7.0 cm (2.76 in) growth which, under these northern conditions, could represent up to an entire season's growth.

Generally there was a progressive increase in height growth variation between the three microsite treatments on unscarified ground. Smaller seedlings were located on the flat microsites, medium seedlings on the sloped microsites and the largest on the humps. On all microsites, including the nonscarified areas the fall planted seedlings out performed the spring planted seedlings although, statistically, the variation was not as significant as that recorded for microsite or scarified-nonscarified differences.

Plantation seedlings were assessed under four additional parameters: injury, degree of frost heaving, quality and degree of shading. Although no statistical comparisons have yet been made among these factors some general observations are possible.

The most prevalent injury recorded was frost damage. In most instances it was apparent that late spring frosts had killed the current year's buds during the early stages of flush. The majority of the frost damage occurred on the Liard River site where the scarification runs in an east-west direction and where there is less residual vegetation present producing a more exposed site and possibly poorer air drainage. Other injuries of possible import include damage from insects (aphids, *Chermes abietis*) and problems caused by high water tables and imperfect drainage which, in low-lying pockets leads to drowning. Throughout there were scattered instances of injury caused by drought, browsing, smothering, burying and erosion, none of which would be considered significant.

Frost heaving of the container plugs occurred ocassionally but was mainly limited to the most exposed sites. The degree of heaving ranged from 0.5 cm (0.2 in), up to 6.0 cm (2.4 in), and in rare cases the plug had been completely heaved out of the ground. As yet it is not a significant cause of seedling mortality.

Seedling quality ratings are based on a subjective assessment of the seedling's appearance and, frequently, variation occurred among assessors. Where frost damage or heavy vegetative competition was prevalent, seedlings tended to be rated as fair to poor. Where constraints to free growth and development were minimized, seedlings were generally rated as good. Relatively few trees were rated as excellent although there were a few trees which had achieved outstanding growth and development.

Degree of shading is assessed on sliding scale ranging from 0 for open to 2 for full shade. Seedlings on unscarified plots were more often under full or partial shade than those on scarified ground which were most often rated open or partially shaded. The scarification appears to have been very effective in checking the invasion of competitive species three years after treatment. It is also apparent that some shading, at least during these initial years of establishment, is beneficial, especially on the scarified plots. Seedlings under partial shade tend to be less affected by frost than those on exposed sites and in many cases are rated higher in overall quality than those under open or fully shaded conditions.

DISCUSSION

Clearly, the main effects of scarification or the absence of it have exerted the greatest influence to date. With respect to the seeding trials unscarified soil produced the lowest initial stocking and establishment regardless of the type of seeding employed or the season of application (Table 1). When compared to treatments on scarified ground highly significant differences in success resulted, all in favor of the scarified treatments.

That some form of seedbed preparation is necessary for successful seeding operations has been well documented (Arnott, 1973; Griffin and Carr, 1973; Richardson, 1973; Stiell, 1976; Zasada, 1969, 1972). Most researchers indicate that creation of a mixed mineral-organic soil seedbed will satisfy most of the biological requirements of spruce seed necessary for germination. Principally, a seedbed with good moisture retaining capacity, an absence of competi-

tive vegetation and a ready source of soluble nutrients will provide adequate environment. Clearly, unscarified ground provides few, if any, of these requirements. Humus or organic layers are poor moisture retaining media if exposed to direct sunlight and they dry out very quickly. The alluvial floodplain sites in the north are fertile enough that vegetative competition, in the form of shrubs, annual and perennial herbs, establishes quickly through vegetative means or prolific seeding unless the old root stocks and residuals are removed. If the organic layers are thick enough, soil temperatures of the mineral layers below can be very cool or cold which, in turn, may greatly reduce the rate of nutrient cycling and decomposition of the organic material (Zasada et al., 1977).

Scarification was applied, on these areas, by means of an angled dozer blade or brush blade. This form of strip scarification created a swath of bare mineral soil devoid of both vegetation and organic material and provided only two of the aforementioned requirements for successional germination. If the weather remains overcast and rainy the mineral soil retains water well, and because of the scalping nature of the scarification, there is no vegetation in close proximity to the germinants to compete for water, nutrients and light. As the growing season progresses and the weather becomes clear and warm these exposed areas will dry and the soil may form a hardpan (if the clay content is high enough) which becomes cracked and fissured. If the upper soil horizons are composed of silts and/or sands they become dry and loosely bound and are subject to aeolian erosion. As well, these very exposed soils are susceptible to frost heaving which may be detrimental to planting operations. However, as the seeding treatments on scarified ground, in these trials, so vastly out-performed those applied to unscarified ground it must be concluded that the exposure of the mineral soil at the time of application of the seed produced enough beneficial effects to allow a moderate degree of success for the broadcast treatments.

The beneficial effects of mineral soil exposure are well defined by Baker (1950): "The infiltration capacity and aeration is good, yet the soil packs well around the seed, which thus secures close contact with films of moisture. The soil has good heat conducting capacity and will warm up faster than the loose organic horizons. There is no great resistance to the process of germination."

If conditions were favorable to initial germination there must be other reasons why the levels of stocking on the seeding trials are only moderately successful at best. Probably the greatest inhibition to increased levels of initial germination and establishment of seedlings on the test sites was surface drying of the soils during warm summer weather. This predisposed the young germinants to mortality through drought or burying caused by deposition of wind borne soil particles. On the Meister site regrowth of vegetation has been abundant and some mortality has been incurred due to smothering. As well, on the Meister site, the absence of a residual strip of mature spruce has resulted in a dearth of seed for supplementary stocking of the direct seeded plots or initial stocking of the controls. It is possible that rodents may have consumed large amounts of seed on both sides. However, this is unsubstantiated.

Stocking levels of the spot seeded plots may be artificially low in that an inadequate amount of seed was sown on the spots as opposed to the treatment itself being defective. Lahde and Tuohisaari (1976) report that for open spot seeding 25-30 seeds per spot should be sown for Scotch pine (*Pinus sylvestris* L.). In this study only six seeds per spot were sown and, while direct comparisons with pine may be questionable, it would appear that the rate of seeding should have been doubled at least.

Generally the data indicate that spring seeding treatments out-performed the fall treatments regardless of the type of seeding used. Arnott et al. (1979) suggest that rodent activity in the fall may be responsible for heavy losses of seed. Analysis indicates that for any given seeding treatment the differences in performance are not significant. Whereas germination and initial establishment (survival) of seed appeared to depend on the presence of a mineral soil seedbed made available through scarification such was not the case with planting. Regardless of microsite, season of planting or the presence of scarified soil, survival of the planted stock was very good indicating that the Styroplug 2 seedlings were of good quality and were well planted allowing for quick establishment of the root systems. Spring planting consistently bettered fall planting; where height growth was concerned exactly the opposite occurred for any given microsite. From comparisons of microsite treatments it becomes apparent that planting on humps is beneficial. The highest survival rates and the best subsequent growth rates were recorded on these sites. Growth rates on unscarified ground were significantly reduced. Increased competition for water, light and nutrients and cooler soil temperatures on these areas have combined effects which have reduced height growth. The overall effects of lesser height growth on these sites have been ameliorated somewhat as frost damage and heaving are much less prevalent on unscarified ground.

Height growth on flat microsites was reduced as well. Soil compaction from the weight of the bulldozer may have resulted in decreased soil aeration and water penetration and the roots of seedlings planted on these sites may have encountered difficulty in penetrating and establishing a root-soil interface on these microsites. These effects will be of a temporary nature and a greater threat to these seedlings will come from frost damage as they are situated on lower sites than those planted on slopes or humps.

The sloped microsites have produced fair to good height growth rates. These sites are elevated and well drained but they are located on the edges of the scarification and are in close proximity to residual vegetative competition. Scarification was applied in a north-south direction on the Meister and an east-west direction on the Liard. Field observation indicated that seedlings on southerly aspects generally performed better.

The humped microsites have produced the best conditions for early seedling growth. These elevated, exposed, loosely compacted soils offered good air and water drainage, easy root establishment and freedom from vegetative competition for the greatest length of time. In some instances the extreme exposure of these sites has predisposed

them to frost heaving and surface drying during warm, clear weather. On humps where some herbaceous vegetation had established to provide some partial shading the seedlings have performed quite well.

At this stage of these trials it is apparent that planting of good quality stock on humped mineral soil sites is the most reliable method of regenerating the alluvial river floodplains of the Yukon Territory. However, direct seeding options should not be disregarded totally. Broadcast seeding applied in the spring on scarified soil hold considerable promise as a reforestation technique. Improvements in scarification techniques to produce a better mixture of mineral soils and organics to create a more stable seedbed with optimum water retention capabilities seem to be the most promising route to follow for ensuring greater success of seeding treatments. To complement this an adequate source of viable seed would be required.

Development of seeding techniques may be necessary in the Yukon as it is doubtful that the level of forest industry there generates enough revenue to support a comprehensive reforestation program based on the planting of stock. Estimates made six years ago revealed that in western Canada seeding costs were approximately CAN $50.65 per hectare (CAN $20.50 per acre) as opposed to CAN $135.90 per hectare (CAN $55.00 per acre) for planting. These figures include the cost of scarification which is the largest single expense in regeneration operations (Richardson, 1973). Other advantages of direct seeding are listed by Robinson (1973) and include: a low requirement for labor and supervision, easy repetition, reasonable cost and convenience for use where access is poor, an important consideration in the Yukon. Some disadvantages of direct seeding include: a tendency towards understocking, high density of stems, uneven distribution, a need for a supply of genetically improved seed, and two or three years' time before adequate stocking is achieved. This latter disadvantage may not be applicable in the Yukon where fall stocking of untreated cutovers may not be achieved on river floodplains for up to 20 years (Nyland 1977).

Other techniques for regeneration may be possible through adept use of alternative harvesting systems such as patch or strip cutting or through shelterwood cuttings. These systems require an increased level of forest management and as yet have not been investigated in the Yukon.

Regardless of which method is ultimately employed to regenerate river floodplains in the Yukon Territory it is important to recognize that there is a need to do it. Although forests north of 60° latitude constitute a relatively minor portion of the commercial forests in Canada there lies a responsibility with foresters to maintain a viable renewable resource wherever it may be.

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SOME CONSIDERATIONS IN THE NATURAL REGENERATION OF WHITE SPRUCE IN INTERIOR ALASKA

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INTRODUCTION

The creation and maintenance of productive forests is a main goal of foresters throughout the high latitude areas of the world. The top portion of Figure 1 suggests one way of visualizing this process. Two points need to be stressed with regard to this Figure. First the compartments or steps are all inter-related. That is, any particular compartment is affected by those which precede it and the activities which occur during that phase of management affect subsequent management activities. Second, within any compartment, there is an array of potential practices. In addition, each individual management practice can be conducted at one of several intensities. These different intensities of management are evident in the high latitude forests of Alaska, Canada and Scandanavia.

The objective of this, and subsequent workshops, is to examine the regeneration phase of forest management in detail. Forest regeneration can also be considered as a group of inter-related activities (Figure 1, bottom half). The statements made above certainly apply to forest regeneration also.

This paper will examine selected aspects of one particular type of regeneration, that is, natural regeneration. For the purpose of this paper natural regeneration refers to those regeneration systems which rely on natural seed-fall for their basic biological input. It also means that various practices can be used for management or treatment of the soil surface to create conditions favorable for germination and seedling establishment. It is obvious that the practice of artificial seeding varies only in that the seed input is assured. In interior Alaska, natural regeneration has been the only means of forest renewal. Because forests cover much of the landscape, it is often believed that natural regeneration occurs automatically following natural or man-caused disturbance. In many cases this is true, however, when some level of forest management is imposed such considerations as length of regeneration period, forest composition, and stand density are frequently not adequate.

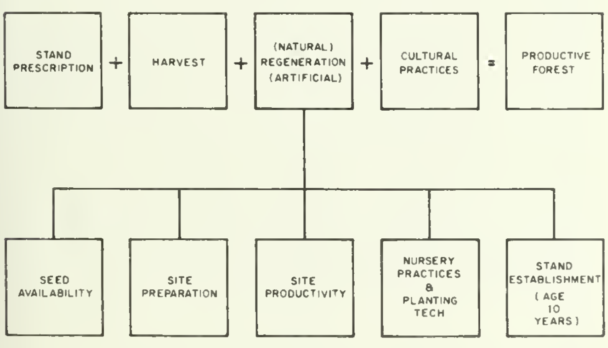


Figure 1.—Elements of productive forest management.

Thus a key question is whether or not foresters and other land managers can take advantage of or direct the regeneration capacity of these forests in order to establish forests of "desirable" composition following harvesting. In other words, can the management alternatives (see Braathe this volume, Zasada et al. 1978a) of harvest and rely on natural regeneration and/or harvest and encourage natural regeneration result in forests of acceptable density and composition?

Natural regeneration of white spruce (*Picea glauca* [Moench] Voss) following harvesting has resulted in varying degress of success. In research studies, where particular care was taken to assure an adequate seed supply and seedbed conditions, large numbers of white spruce seedlings have resulted (Zasada et al. 1978b, Zasada and Grigal 1978, I.N.F. 1979, unpublished). In areas harvested operationally prior to the early 1970s, no particular attention was paid to obtaining regeneration, and white spruce stocking has been less than adequate in many cases (Fox, 1979 personal communication; Clautice, 1979 personal communication, I.N.F. 1979 unpublished).

These Alaska results and observations confirm what has been the general experience with white spruce throughout much of the North American boreal forest and, in particular, western Canada (Dobbs 1972, Zasada and Gregory 1969). That is, adequate natural regeneration of white spruce is difficult to obtain without a management flexibility that includes assuring an adequate seed supply and seedbed conditions.

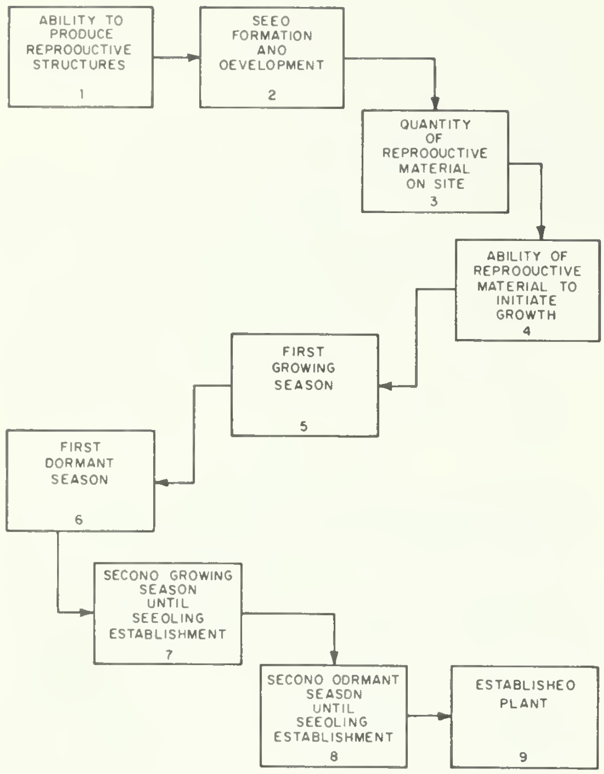


Figure 2.—Diagramatic representation of natural regeneration of white spruce in Alaska.

Natural regeneration of white spruce is without a doubt a complex process perhaps more complex than for any other tree species in Alaska (Zasada 1971). The process involves a number of discrete but closely related steps (Figure 2). In the following discussions, I would like to consider the aspects of regeneration represented in this diagram. The discussion is by no means exhaustive. I have selected an example for each compartment which indicates the type of considerations necessary for assessing and understanding this regeneration method.

COMPARTMENT 1

Ability to Produce Reproductive Structures

Explanation: The production of white spruce cones varies annually and is dependent on such factors as tree age, the previous years' weather conditions, previous cone and seed crops and other factors (Matthews 1963, Anon 1974).

Example: Table 1 illustrates several points concerning annual variation in cone production. (1) During the 10-year observation period there were 3 years when there was little or no cone production. One feature of these years is that they generally follow years of high cone production. (2) Most of the trees followed the same general pattern of cone production. However 2 of the 15 trees (numbers 13 and 15) appeared to be generally poorer cone producers, particularly, over the last 6 years of the period.

COMPARTMENT 2

Seed Formation and Development

Explanation: This compartment considers all factors which interact to determine the quantity and quality of the seeds available for dispersal in late August or early September. These factors include physical environmental variables (particularly termperature) and biological variables such as insects, disease and squirrels.

Example: Zasada et al. (1978b) have discussed many of the considerations pertinent to this compartment. The effect of temperature on seed quality is one point that needs to be stressed. There are two general effects of temperature. First is death caused by subfreezing temperatures. Developing cones are particularly susceptible at the time of pollination. This damage has been observed in Alaska. The second temperature effect is more subtle and occurs when summer temperatures are not warm enough for developing seeds to mature. This phenomenon has been observed in Alaska in higher elevation stands and in some areas north of the Arctic Circle. It is a well-documented and serious problem in northern Scandinavia and needs to be more fully understood in Alaska.

COMPARTMENT 3

Quantity of Reproductive Material on the Site

Explanation: The quantity of seed available for dispersal will be determined by the amount of filled seed on the tree in late August, its dispersal and fate once it reaches the seedbed.

Example: White spruce stands throughout much of interior Alaska are capable of producing large quantities of seed

Table 1.— Annual cone crops for 15 trees in a white spruce stand near Fairbanks, Alaska*

Tree	Year									
No.	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
1	1	500	0	750	82	0	500	0	450	220
2	3	1100	0	1600	0	0	600	0	700	5
3	0	1300	0	500	125	0	375	0	500	10
4	0	700	0	650	46	2	275	0	250	0
5	0	550	0	300	26	0	225	0	260	0
6	32	585	0	500	43	0	225	0	300	30
7	20	415	0	350	15	0	200	0	100	0
8	8	775	0	525	45	0	175	0	150	25
9	0	420	0	650	22	5	425	0	250	50
10	18	360	0	575	10	0	85	0	100	75
11	90	271	0	575	0	0	50	0	300	1
12	1	400	0	525	0	0	175	0	200	0
13	6	850	0	125	0	0	0	0	10	0
14	0	900	0	300	147	1	275	0	450	0
15	29	470	0	325	17	0	65	0	75	12

*Cone counts made from a fixed point for each tree.

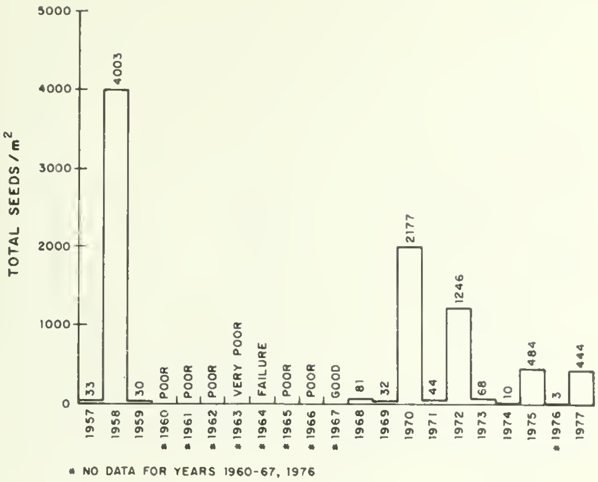


Figure 3.—Seedfall in a stand near Fairbanks, Alaska.

(Figure 3). In some cases these large seed crops occur at close intervals. For this particular stand, there was seed available in relatively large quantities in 4 out of 10 years. Seed crops of about this magnitude have resulted in large numbers of seedlings on mineral soil seedbeds (Zasada et al. 1978, I.N.F. 1979, unpublished data). Filled seed varied between 55 and 60 percent of total seedfall for these years.

COMPARTMENT 4

Ability of Reproductive Material to Initiate Growth

Explanation: This compartment deals with the factors controlling germination of white spruce. There are probably always periods during a given summer when germination can occur. However, there are also periods during the growing season when germination is prevented by one or more environmental factors (Zasada et al. 1978b, Clautice et al. 1979, Ganns 1977).

Example: Two basic patterns of white spruce seed germination have been observed in interior Alaska. The first is where germination begins in mid-late May and occurs with little or no interruption over about a 3-4 week period. In this case 90 percent or more of the germination occurs by late June (I.N.F. 1979, unpublished data). The second basic pattern is illustrated in Figure 4. Germination begins as in the first pattern but because of adverse conditions it is interrupted in June to early July. It resumes in late July or early August as environmental conditions become favorable again (Zasada et al. 1978b, Ganns 1977). Clautice et al. (1979) have observed a pattern that suggests that the early peak in germination is prevented by low temperatures on higher elevation sites. These germination patterns can be significant in terms of seedling survival.

Figure 4.—Seasonal germination pattern for white spruce: 1971.

COMPARTMENTS 5 AND 6

First Growing Season Survival

Explanation: Seedlings are most susceptible during the first year following germination. A range of factors affect their survival and many of these factors never will be as critical again during the life of the tree. The growing season and dormant season are separated because of the different nature of the factors affecting survival.

Example: First growing season and dormant season survival is affected by the time at which germination occurs as this will determine the time available for growth and the range of conditions to which the seedling is exposed during the first year (Figure 5; Zasada et al. 1978b). Unpublished data for germination pattern 1 (see above) tends to substantiate these observations.

COMPARTMENTS 7 AND 8

Factors Affecting Seedling Establishment and Survival During the 2nd and Subsequent Seasons Prior to Establishment

Explanation: As in compartments 5 and 6, the growing and dormant seasons are separated because mortality during one

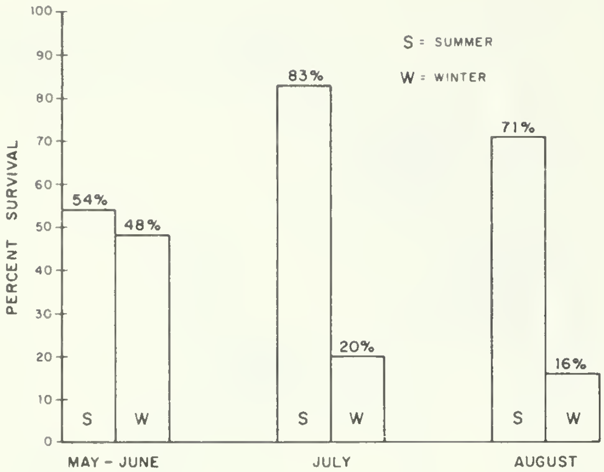
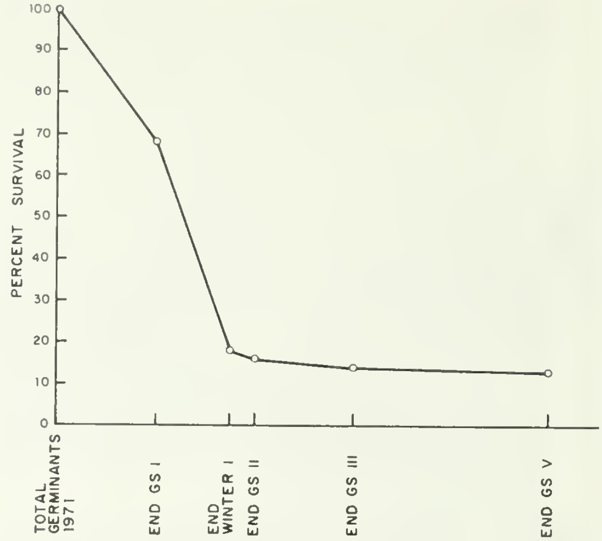
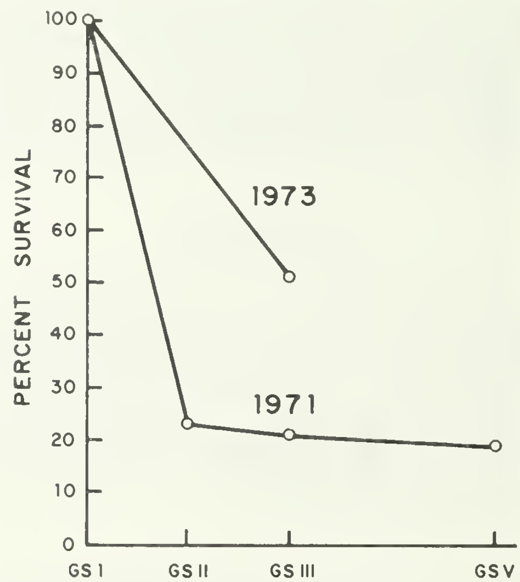


Figure 5.—Summer and winter survival of white spruce seedlings germinating during May-June, July, and August.



A: 1971 white spruce germinants.



B: 1971 and 1973 white spruce germinants.
Figure 6.—White spruce seedling survival over five growing seasons.

or the other of these periods suggest that different sources of environmental interference are affecting establishment.

Example: Seedling survival and seedling growth are separate yet related considerations in compartments 7 and 8. From the information available for Alaska, there are several points that can be stressed concerning survival. First although mortality occurs during this period it is greatly diminished from that which occurs during the first year after germination (Figure 6; Zasada et al. 1978b, I.N.F. 1979, unpublished data). Second the mortality that occurs appears to be greatest among those seedlings that germinated late in the first growing season (Figure 7). Finally, seedlings produced from seed of later crops is less efficient in terms of the number of seeds/seedling. This indicates that seedbed conditions deteriorate rapidly.

Seedling growth is affected by the type of seedbed. The location of the seedling on the scarified seedbed may affect the growth rate and thus seedling establishment. Zasada and Grigal (1978) reported that 3-year-old seedlings were over two times larger (dry weight) on mineral soil surfaces than on debris surfaces. Unpublished data show that after 5 years white spruce seedlings are significantly taller and have a larger based diameter than those on organic matter surfaces.

Because of the greatly improved success of white spruce regeneration on mineral soil surfaces some mention must be made of this as it relates to compartments 5-8. First of all there are going to be obvious differences in mineral soil quality between soil types (e.g. upland soils compared to floodplain soils). Within a general soil type, in fact, within a scalped area there may be a number of different site conditions with regard to seed germination and seedling growth and establishment. Figures 8 and 9 indicate large point to point differences that can occur in white spruce (and paper birch) seedling density and height. In other words these data suggest that although mineral soil surfaces may seem homogeneous relatively large microsite differences can occur over a short distance and have a large effect on seedling survival and growth. Finally seedlings of other trees and shrubs also regenerate best on mineral soil seedbeds and will compete to varying degrees with various environmental resources.

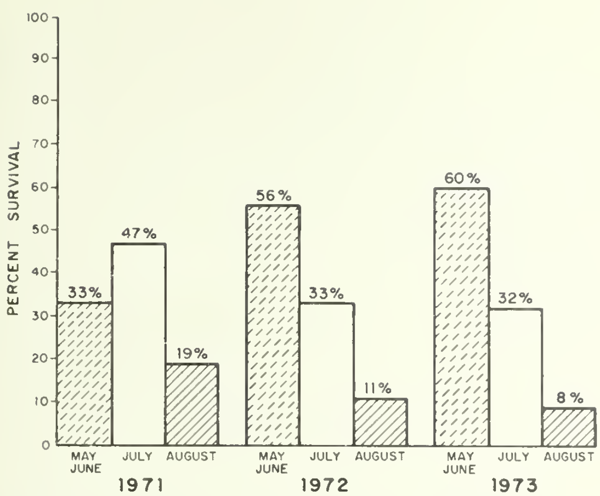


Figure 7.—Composition of white spruce seedling population in 1971, 1972, and 1973 by period which germination occurred.

Figure 8.—Variation in seedling height on a scalped seedbed.

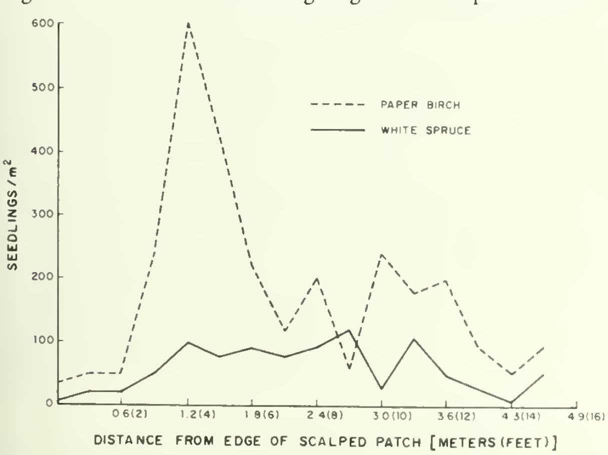


Figure 9.—Variation in average seedling density on a scalped seedbed.

SUMMARY

Natural regeneration of white spruce is a complex process. However, it has been demonstrated that abundant natural regeneration can be obtained given a good seed source and a mineral soil seedbed. The method of regeneration is a viable alternative on those sites where the land manager has the flexibility to time site preparation with the occurrence of seed years.

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ALASKA REGENERATION: STATE POLICY AND PROBLEMS

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INTRODUCTION

Alaska is a vast state with a total land area of 148 million hectares (365.5 million acres), about 16% of the total land area in the United States. Its forested land, both coastal and interior, totals 48.2 million hectares (119 million acres), which is about 16% of all forest land area in the United States. Of this 48.2 million hectares, only 11.4 million are considered commercial, defined as capable of growing 1.4 cubic meters of wood per hectare per year (20 cubic feet/acre/year). British Columbia, by comparison, has 25.651 million hectares of forest lands producing over 1.12 cubic meters per hectare per year (16 cubic feet/acre/year) (Reed and Associates, 1978). Alaska's coastal forest contains 5.363 million hectares (13.25 million acres) of which 2.3 million hectares (5.75 million acres) are commercial. This area is only 20.4 % of Alaska's total commercial forest area, but it is the most productive, containing almost 85.6% of the net saw log volume and 70.8% of the growing stock (Hutchison, 1967). The remainder is Alaska's interior forests. Alaska's forests have been fairly well defined but their ownership is not.

The Alaska Statehood Act of 1959 allowed the state to select 41.8 million hectares (103.3 million acres) of land from the federal domain. Twenty years after the Statehood Act, there is still about 65% of the state's entitlement to be transferred. As of October 31, 1979, the state has only received final patent on 8.2 million hectares (20.2 million acres) and has tentative approval on an additional 6.7 million hectares (16.5 million acres). Much of the state-selected land has been chosen for non-forestry uses. A good example is the state's ownership of the Prudhoe Bay oil fields on the north slope of the Brooks Range. Another factor is the Alaska Native Claims Settlement Act (ANCSA) of 1971 which allows Alaskan Natives to select 16.2 million hectares (40 million acres) of the public domain in exchange for relinquishing all future land claims. Under this law the Natives have selection priority; they have selected large amounts of profitable forested land in Southeast Alaska and, to a lesser extent, done the same within the interior.

In short, Alaska's interior forests are generally undefined and unmanaged. They will remain so until the issue of who owns and who will manage them is determined.

FOREST MANAGEMENT

There are four principle public land management agencies within the State of Alaska: the U.S. Forest Service, the Federal Bureau of Land Management, the Federal Bureau of Indian Affairs, and the Alaska Department of Natural Resources (Division of Forest, Land and Water Management). All of these agencies are, to one extent or another, involved in harvest and regeneration of forest lands within Alaska. The relative size of the management efforts of each agency is shown in Table 1. These volumes reflect sales, not actual harvest, of the four agencies since 1969. As such, they reflect management policy. Note the effect of the Alaska Native Claims Act after 1971.

Management activity developed within the more accessible, productive forest of coastal Alaska. The major stimulus was the U.S. Forest Service's fifty year contract with the Ketchikan Pulp Company for 42.5 million cubic meters (1,500 million cubic feet) of wood. It was signed in 1951 and a pulp mill was built by 1954. Another large contract was signed by the Forest Service in 1956 with the Alaska Lumber and Pulp Company for 27 million cubic meters (5.25 billion board feet). This wood was primarily destined for Japanese markets. The State of Alaska signed a negotiated long-term 15-year contract in August 1979 with the Schnabel Lumber Company, Haines, Alaska. Under provisions of this contract, the purchaser will harvest 5,600 cubic meters annually (10.8 million board feet). Natural regeneration on these coastal forests has been very successful because of high rainfall, mild climate, and excellent seed years. Alaska's interior forests, however, are more remote, less productive, and climatically more severe (Zasada, 1976). They have less management activity and more difficult regeneration. These problems will be addressed as they relate to state-managed forest land.

The State of Alaska manages forest land within both the coastal and interior forests. With the exception of the state's long-term timber sale at Haines, there is relatively little state forest land in the coastal forest. The greatest amount of state forest land is (and will be) in the interior. Figure 1 illustrates the relative amounts of actual, harvested wood from the two different forest types. State management policy for these lands derives from sections one and four of the Alaska Constitution:

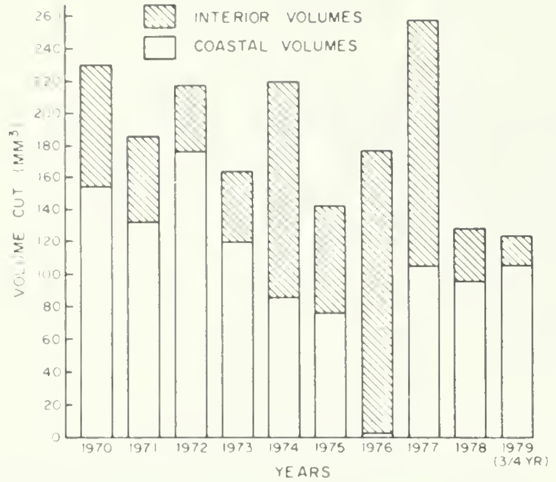

Figure 1.—Volume cut, Alaska state lands, 1970-1979.
SOURCE: Monthly Cut-and-Sold Reports, Department of Natural Resources, State of Alaska.

Section 1. It is the policy of the State to encourage the settlement of land and the development of its resources by making them available for maximum use consistent with public interest.

Section 4. Fish, forests, wildlife, grasslands and all other replenishable resources belonging to the State should be utilized, developed, and maintained on a sustained yield principle, subject to preferences among beneficial uses.

Alaska has fewer than 809,000 hectares (2,000,000 acres) classified for state forest management. As a result, there are few inventories, no forest management plans and, until recently, no written regeneration policy. Sales have generally been the result of economic and political pressure. Until a stable forest land base is designated, the situation is likely to remain this way.

The major harvest activity within the Interior is the State's Westside Salvage Sale located west of Anchorage, across Cook Inlet. Over 90,000 hectares (223,000 acres) of mixed white spruce (*Picea glauca* [Moench.] Voss) and

Table 1: Volume of timber sold on publicly owned or managed lands in Alaska, 1969-1978.

	U.S. Forest Service		State of Alaska		BLM		U.S. Bureau of Indian Affairs	
Year	MBF[a]	MM^3[b]	MBF	MM^3	MBF	MM^3	MBF	MM^3
1969	214,436	1,104.02	247,679	1,275.17	447	2.30	2,931	15.09
1970	349,066	1,797.16	14,926	76.85	554	2.85	9,885	50.89
1971	79,586	409.75	40,510	208.56	346	1.78	2,338	12.04
1972	33,445	172.19	23,109	118.98	4	0.02	40,052	206.21
1973	73,781	379.86	309,451	1,593.20	5	0.03	3,342	17.21
1974	127,941	658.70	21,146	108.87	174	0.90	8,787	45.24
1975	147,018	756.92	4,655	23.97	930	4.79	7,060	36.35
1976	15,619	80.41	2,358	12.14	215	1.11	0	0
1977	80	0.41	2,412	12.42	54	0.28	0	0
1978	170,790	879.31	6,932	35.69	142	0.73	440	2.27
Total	1,211,762	6,238.73	673,178	3,465.85	2,871	14.79	74,835	385.30

[a]Thousands of board feet, Scribner log rule.
[b]Board foot conversion: 1 M^3 = 35.315 ft^3, board foot to cubic foot ratio = 5.5 BF/1CF.

SOURCE: Ruderman, 1978.

Table 2: Harvest area and volumes at Westside Salvage Sale, Tyonek, Alaska.

	AREA		VOLUME					
			Spruce		Hardwoods		Total	
	Hectares	Acres	MBF	MM^3	MBF	MM^3	MBF	MM^3
1975	1,323	3,269	10,720	45.99	0	0	10,720	45.99
1976	2,807	6,936	31,702	136.01	7,629	32.73	39,331	168.74
1977	2,456	6,070	14,952	64.15	19,013	81.57	33,965	145.72
1978	686	1,695	2,812	12.06	2,078	8.92	4,890	20.98
1979	476	1,177	3,196	13.71	1,776	7.62	4,972	21.33
Total	7,748	19,147	63,382	271.92	30,496	130.84	93,878	402.76

SOURCE: State of Alaska, Department of Natural Resources, Division of Forest, Land, and Water Management, South-central District.

hardwood forest was attacked near Tyonek by spruce bark beetles (*Denroctonous rufipennis* Kby.) between 1969 and 1972. This area was reattacked in late 1978 and 1979, resulting in an additional 121,000 hectares (300,000 acres) of newly killed spruce. Because of the severity of the attack, there are few natural seed sources and most regeneration is either residual conifers or hardwoods. No natural white spruce seedlings have been found. Table 2 shows harvest volume and area for this sale. Regeneration efforts have been limited to small test plantings, a direct seeding trial, proposed prescribed burning and mechanical scarification tests, and a proposed seed tree regeneration cut. Much of the adjacent land was selected by the Cook Inlet Native Corporation and two municipal boroughs (i.e., counties). These selections will require cooperation and closely coordinated efforts to retain productivity of these immense forested areas.

The lack of regeneration within the interior is widespread. An examination near Fairbanks indicates only 30% of the harvested areas were stocked with acceptable seedlings. It is likely that silvicultural systems and direct seeding on scarified areas will be a solution to this problem. Hand planting will be needed in some areas. Efforts toward solving these problems have been further emphasized by the State's Forest Resources and Practices Act.

FOREST RESOURCES AND PRACTICES ACT

The Forest Resources and Practices Act became effective January 1, 1979. It reflects four years of review by many concerned individuals and interest groups. Basically, it has two purposes: it is enabling legislation for state forest management and it is regulatory legislation for forest practices. Draft regulations are currently being written for public review and comment; however, the regeneration provisions of the act now state:

> With respect to state, municipal and private forest land the following standards apply:
>
> (4) To the fullest extent practicable harvested land should be reforested, naturally or artificially, so as to result in a sustained yield of merchantable timber from that land; if artificial planting is required, silviculturally acceptable seedlings must first be available for planting at an economically fair price in Alaska. With respect to state and municipal forested land only, the following standards also apply:
>
> (1) Forest land shall be administered for the multiple use of the nonrenewable resources and for the sustained yield of the renewable resources of the land in the manner which best provides for the present and preserves the future options of the people of the State of Alaska.
>
> (4) Timber harvesting is limited to areas where data and information demonstrate natural or artificial reforestation techniques will result in the production of a sustained yield of merchantable timber from that area.
>
> (5) There shall be no significant impairment of the productivity of the land and water with respect to renewable resources.

This act sets forth clear policy for the management of the state's forested lands. It also emphasizes reforestation on private lands within Alaska. A prime tool for implementing this policy is the State Forest Nursery at Palmer. Without this facility, management options are severely limited. A capital budget was recently compiled and submitted by the Division of Forest, Land and Water Management. In part, it stipulated moving the nursery to Eagle River to heat with lower cost natural gas, thereby meeting the "economically fair price" provisions of the act.

Direct Seeding

Direct seeding is still basically a research activity in Alaska. Most of the work has been conducted by Dr. John Zasada at the Institute of Northern Forestry (U.S. Forest Service). The state has conducted direct seeding trials at the Willow Experimental Forest northwest of Anchorage, and at the Westside Salvage Sale. Tests include both artificial and natural seeding on scarified and nonscarified ground. Application rates at the Westside Salvage Sale were 1.14 kilograms/hectare (2.5 pounds/acre) and 0.57 kilograms/hectare (1.3 pounds/acre) of white spruce seed from a Kenai Peninsula seed source.

Direct seeding success elsewhere shows much promise. A critical factor in Alaska is available seed for production work. Variables affecting Alaskan cone crops are largely unresearched and need much closer examination; research near Fairbanks, for example, indicates high variability of cone production within a single year (Zasada, 1978).

Silvicultural Systems

Preliminary trials of various silvicultural systems within the interior indicate some success. Shelterwood cutting near Fairbanks produced regeneration of both hardwoods and softwoods (Zasada, 1978). A proposed seed tree cut of white spruce at the Westside Salvage Sale will be implemented soon. Hardwood regeneration has shown variable response in Alaska and much development in this area is likely as the costs of artificial conifer regeneration remain high.

Tree Improvement

The first exotic trees planted in Alaska were Sitka spruce (*Picea sitchensis* [Bong.] arr) transplanted from Sitka to Unalaska (on the Aleutian Chain) by a Russian priest in 1805 (Lutz, 1963). Several are still growing today (Tindall, 1979). Preliminary research indicates several species have much potential in Alaska. Species tested so far include Siberian larch (*Larix sibirica* L. deb.), Scotch pine (*Pinus sylvestris* L.), lodgepole pine (*Pinus contorta* Dougl. ex Laud), and Norway spruce (*Picea abies* [L.] Karst).

Reforestation needs indicate planting of genetically improved trees is likely. A potential 10% increase in yield makes this program very appealing to forest managers. The developing land base suggests cooperative efforts among the various government agencies, large Native land holders, and other individuals are possible. For the present, basic genetic improvement steps, such as writing preliminary seed zones and transfer rules, are being developed.

FUTURE PROGRAM DEVELOPMENT

Policy

Draft legislation was submitted in September 1979 for a State Reforestation Fund. As conceived, this fund would set aside 50% of the gross stumpage receipts for reforestation purposes. The three state land management districts would develop a reforestation plan for each sale and draw necessary money from the fund. It is similar to other funds such as the Federal Knutson-Vandenburg Fund. This Reforestation Fund would provide the firm economic base needed to implement reforestation provisions of the Forest Resources and Practices Act.

Research

There is a continuing need for applied research on site scarification, prescribed burning, mechanized planting, basic planting technology, and further testing of containerized seedlings. Much research will be needed in the harvest process as it relates to stand establishment. The forest manager must continue administrative studies on plantation survival and growth. The cost of planting, time required, most likely planting periods, and characteristics of planting stock must be analyzed and recorded. In addition, managers must continue testing regeneration survey techniques.

SUMMARY

The Alaska Native Claims Settlement Act and the Alaska Statehood Act determine ownership and management of Alaska's 42.8 million hectares (116 million acres) of interior forests. Of the four public forest land management agencies, the State Division of Forest, Land and Water Management is responsible for implementation of the recent State Forest Resources and Practices Act. Its reforestation provisions create clear policy for state, municipal and private forest land. Other reforestation program elements are the State Forest Nursery, testing (direct seeding, silvicultural systems) and a tree improvement program. Future research will answer many management questions and the proposed Reforestation Fund will held fund them.

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EXPERIENCES AND PRACTICES RELATED TO FOREST REGENERATION IN NORTHERN SWEDEN

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THE PICTURE AND THE FRAMES

Sweden is a very long country and the climatic, geologic and economic conditions for forestry vary greatly. In the south there are Beech forests and high productive spruce sites. In the north is the natural northern limit of the coniferous forests with a hard climate, short growing season and low yield. Up here both biologic and economic problems of survival are dominating.

The following will mainly deal with the forests north of latitude 60°N. Approximately at this latitude one finds a plant-ecologic and climatic border line that well separates the less productive and more sparsely populated northern forests.

Within this region forests with Scotch Pine (*Pinus sylvestris* L.) and Norway Spruce (*Picea abies* [L.] Karst), mixed with 10-20% hardwoods, are dominating. There are soils from sandy sediments to dense moraines. The most common is the sandy-loamy moraine. There are forest vegetation types from wet peatlands to extremely dry lichen heaths. The most common is the mesic Vaccinium dwarf-shrub type. The landscape is not very mountainous. The elevation raises from the coast in the east up to the tree limit at 600-700 m (2000-2300 ft) in the mountain range in the west. The precipitation varies between 400 and 700 mm per year (16-28 in/year) and the length of the growing season decreases from 130-140 days in southeast to about 100 days in northwest. The average wood production on productive forest land is 2-3 cubic meters per hectare per year (30-40 cubic feet/acre/year). The annual cut is about 35 million cubic meters (1.2 billion cubic feet) which is about the same as the total annual growth. Several factors, such as long transportation distances, difficult snow conditions, cold and short winter days and high silvicultural costs guarantee a weak economy with low returns. When timber prices and business cycles are varying, an economic roller-blind is drawn back and forth over the inner parts of the area.

In the west and the north along the mountain range there is another important border—the exploitation limit. It is situated 100-200 m (330-660 ft) below the upper tree limit. It was drawn across all Forest Service land some 30 years ago and it eliminates 600,000 hectares (1,482,600 acres) of forest land. No clear-cuts are permitted above this limit. Long experience has shown that at those extreme sites it is so difficult, risky and expensive to regenerate new forests within a reasonable time that we must wait until better methods have been developed. Some research projects with, for instance, exotic tree species are going on.

According to the Swedish Forestry Act every cut down forest must be replaced with a new one with high and valuable yield. The act also prescribes the lowest ages for final felling and rules for rationing the fellings in order to get an even and sustained yield.

THE HISTORY

During the 19th century the sawmilling industry grew up and the biggest and best trees were picked out from the forests. This high grading of vast areas resulted in gradually more open and older forests. The situation became unsatisfactory. At the turn of the century the pulp industry was born which created a need for smaller trees and tree parts as well. The preconditions for modern forestry were established. But how should the forests be regenerated? The debate was hard between the "clear-cutters" and the "selection-fellers." The latter wanted to continue the gradual thinning of the stands in order to get new plants in the openings without any costs for planting or seeding. This method dominated from 1920 to 1940 but the result was a disaster. No plants appeared and the back of the old stand was broken.

The reason was a lack of understanding for the ecological conditions of forest regeneration in these poor areas. In the stand exists a hard competition for the limited conditions of life, especially accessible nitrogen. Different species and individuals are living in a narrowly regulated balance. The small and the weak have no chance to break through.

Research and experience have shown that the key problem was to regulate this competition in favor of the new stand. The balance must be radically altered. This altering starts with a total final felling and is fulfilled with different complementary measures, e.g. burning or scarification, depending on the vegetation type and thickness of the humus layer. In this way the principles of today's clear-cut method were developed.

THE GOALS

The forest of today offers a variety of useful products. Tomorrow we might use it in another way. By establishing new stands and managing them we can influence and direct the growth towards certain goals.

Some principal goals for the Forest Service are:

1. The vitality of the forest shall be maintained and preferably improved.

2. The production in older and middleage stands shall be directed towards high quality sawtimber.

3. Coniferous species shall be used mixed with 10-15% hardwoods.

4. The new stands shall be managed to offer a future freedom of choice of the final goals so that the wood production capacity of the site is well utilized.

5. The uneven age class distribution shall be compensated by a planned set of measures which result in shorter rotation periods and higher yield.

6. The beauty of the landscape shall be preserved as far as possible and people's recreation and outdoor life shall be facilitated.

THE SILVICULTURAL PROGRAM

About half the clear-cut area is naturally regenerated with seed trees (50-75 trees per hectare; 20-30 trees per acre). Most of this area is dry and poor pine sites. The other half is artificially regenerated by planting or direct seeding. In most cases pre-regeneration cleaning and scarification is made.

Today scarification is mainly done with continuously working harrow type scarifier. The use of patch scarifiers has decreased. Limited areas with wet and cold soils are ploughed with deep cultivators. Burning has almost ceased.

Planting is the dominating method in artificial regeneration. Direct seeding is used only on a small percent of the area. Containerized seedlings from greenhouse nurseries are dominating.

The goal of the regeneration is about 2,000 main crop plants per hectare (800 per acre). A systematic plant survey followed by necessary repair planting is made after 2-3 years. On 10-15% of the land the hardwood slash vegetation usually makes a special spraying with herbicides necessary.

When the trees reach the height of 2-4 m (7-13 ft) a pre-commercial thinning is made which reduces the number of stems to 1,200-1,800 per hectare (485-730/acre). The lowest figure stands for the poorest and technically difficult sites where a further thinning will be economically dubious. The first commercial thinning is done at the height of 13-14 m (43-46 ft) and the number of stems by the final felling usually is 400-700 per hectare (160-280/acre).

Well situated older and middleaged stands are fertilized every 6-7 years with 150 kg nitrogen (N) per hectare (134 lbs/acre).

THE PROBLEMS

No activity is without problems and each problem initiates development of new methods. In the following the main problems and some development activities are described.

Bad Regeneration Results

To establish a new forest is difficult. It is very easy to fail. A lot of money is used for repair planting. The trend is positive today but the result can still be improved. Some important subjects are: seed problems, site preparation methods and plant supply.

Seed problems: The closer the natural tree limit the rarer the trees will flower and the more unsufficient will the conditions for good seed ripening be. There are often 10 years between average seed years and 20 years between peak years. Figure 1 shows the seed ripening of Scotch pine 1979. There are some possibilities to pick the cones early and let them ripen during proper storage before the extraction.

The difficult situation of seed supply is a temptation to get ripe seed from southern areas. The experiences of this is disasterous. Large areas of young pine plantations have gradually died during the first 20 years after planting due to wrong selection of provenances and to low hardiness.

Figure 2 summarizes the result from a 20 year old test plantation at Bjorkvattnet. This is a typical result. The problem of provenance choice in northern Sweden is to optimize the demand for hardiness and the demand for good growth of the individual tree. The figure illustrates this optimization problem. It can be looked upon as a map. Along the X-axis, the coastline as well, the latitudes are marked and along the Y-axis the altitudes are marked.

The elevational tree line is also marked and the area beneath this line is the natural area of Scotch pine in northern Sweden. The location of the test site is marked with a shaded square. The solid lines are regression lines, showing the variation in survival ability with regard to the original latitude and the altitude of the tested provenances. For instance, provenances which originate from localities along the solid line marked "50%" will survive to approximately 50% after 21 years when planted at Bjorkvattnet. Provenances originating from localities along the line marked "75%" and "90%" will survive to 75% and 90%, respectively, if moved to Bjorkvattnet. It is obvious that provenances from the north have survived better. Provenances from the areas surrounding the experiment have

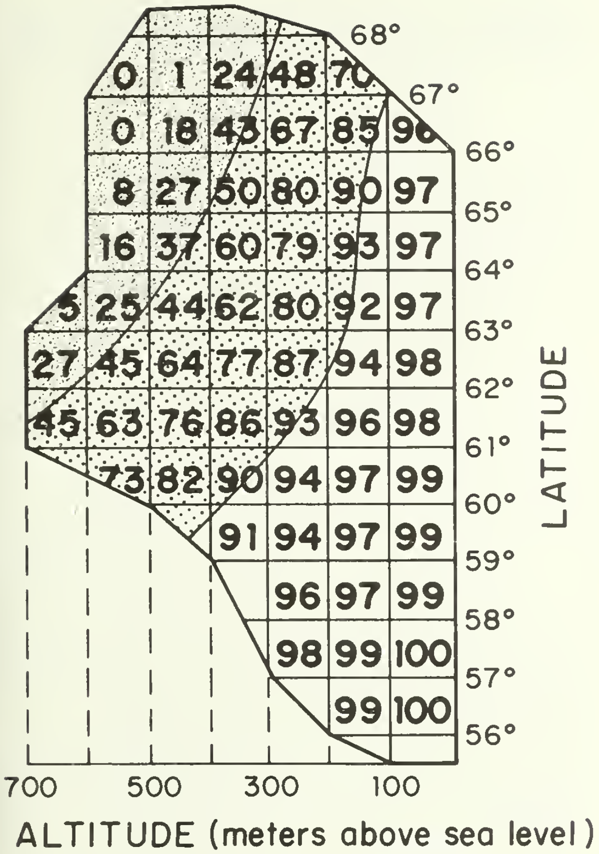


Figure 1.—Expected germination, per cent of seed from different latitudes and altitudes, 1979-80.

survived to about 60-50%. Concerning survival ability pine seed should be moved from north to south.

However, the demand for hardiness must not be given such a high priority that the individual trees utilize the vegetation period inefficiently, which results in poor growth. Every tree has a genetically dependent growth rhythm, which means that the trees start and terminate their annual growth in a programmed manner. Provenances too far from the north contain a large share of early terminating individuals which do not utilize the gowing season well and therefore will grow slowly.

The upper broken line in Figure 2 shows the relationship between the mean height of the provenances and their original latitude. It is obvious that southernmost provenances have a lower height. They are not hardy enough and therefore their condition is not the best. It is also obvious that the most northern provenances have a lower mean height as well. This agrees very well with the theory above. However, the curve has no clear maximum. Within the optimum interval the values of the different provenances have a fairly large variation around the curve, which may be considered as an expression of specific genetic values for different progenies.

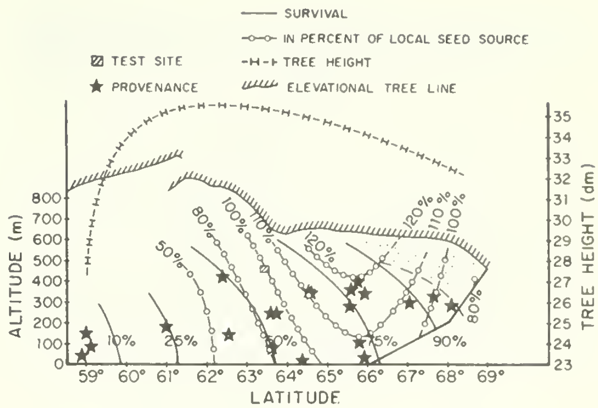


Figure 2.—Survival, tree height, and wood production per hectare in Bjorkvattnet related to the origin of the provenances.

The best criterion when choosing the right provenance is, however, the highest wood production per hectare. The lines with dashes and rings (Figure 2) illustrate this production in the following manner. Provenances which originate from localities along the line which passes through the square of the test site will produce approximately as much as the local provenance (= 100) if grown at Bjorkvattnet.

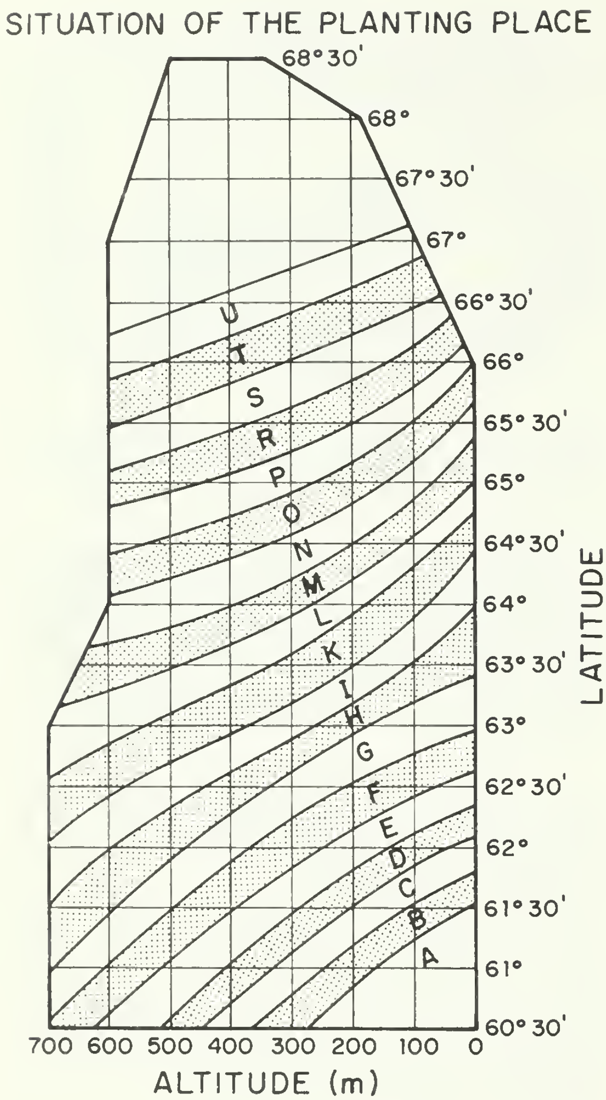
Provenances which originate from the same altitude but about two degrees of latitude further north will apparently produce 20% more when grown at Bjorkvattnet. When moving provenances even further from the north the production will decrease again.

The results have been summarized in a "Seed transfer scheme" (Figure 3) which in concise terms shows that pine seed in northern Sweden should always be moved from north to south and the further from the north the closer to the tree line or further to the north the planting site is situated. On the average the scheme will result in 70-80% surviving plants after 20 years in the field.

Such seed transfer schemes have been developed for Norway spruce and lodgepole pine (*Pinus contorta* Dougl. ex Laud.) as well. They are critical tools in the regeneration work.

An extensive seed orchard program has been established through selection of plus trees within different zones, grafting and so on. About 50% of the pine seed supply comes from those orchards today and the crops are increasing. In northern Sweden, of course, it is of special value to have an even supply of ripe seed from seed orchards situated in areas with good climate. Besides that the new seed results in new forests with 20% better growth.

Site preparation methods: A good site preparation is of fundamental importance for the establishment of plants or seeds. It breaks the competition from other vegetation, improves the supply of nutrients, raises the soil temperature, improves the drainage, reduces the risk for frost and facilitates the planting.



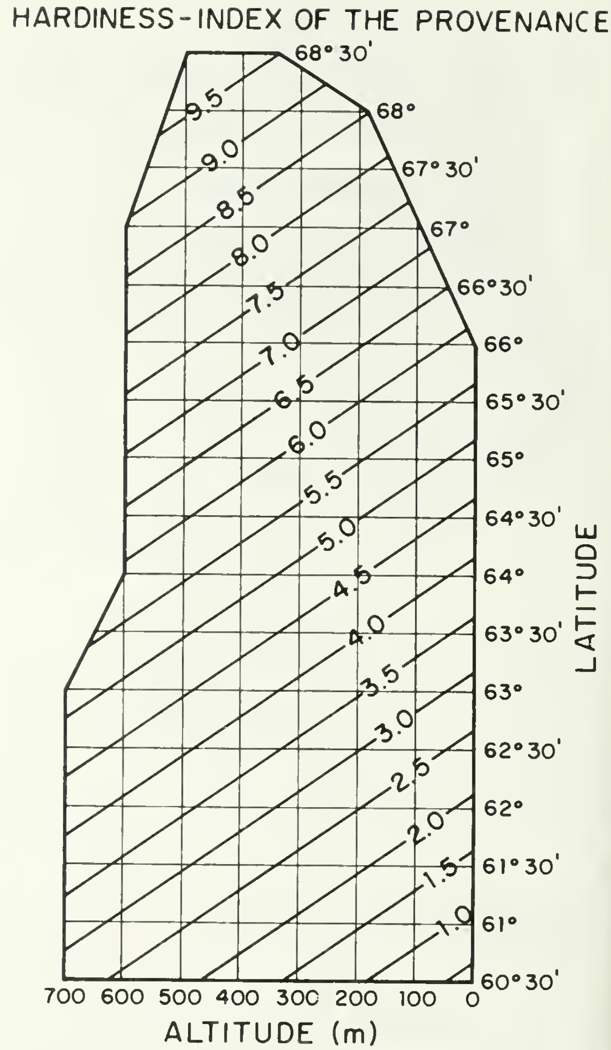


Figure 3.—Seed transfer scheme by planting Scotch pine in northern Sweden. NOTE: One unit higher hardiness—index than recommended means about 10% lower production due to slow growth. One unit lower hardiness—index than recommended means about 10% lower production due to bad survival.

AREA	Recommended hardiness—index
A	0—1.5
B	1.0—2.0
C	1.5—2.5
D	2.0—3.0
E	2.5—3.5
F	3.0—4.0
G	3.5—4.5
H	4.0—5.0
I	4.5—5.5
K	5.0—6.0
L	5.5—6.5
M	6.0—7.0
N	6.5—7.5
O	7.0—8.0
P	7.5—8.5
R	8.0—9.0
S	8.5—9.5
T	9.0—10.0
U	9.5—10.5

Some of our specified demands to the manufacturers of machines are:

1. Expose mineral soil on an area of at least 30 dm^2 (46.5 in^2).

2. Loosen the soil to the depth of 10 cm (4 in).

3. Make small piles or other elevated planting spots.

4. Cause as little disturbance of the environment and the landscape as needed.

Earlier burning was very commonly used and the results on the right kind of sites are very good. Lack of labor and a troublesome time planning situation has made burning expensive and difficult to organize. Development projects, e.g. with lighting and extinction from helicopter, are going on.

A couple of site preparation machines with movable buckets which are making soil piles are being developed. The result is very promising. On technically very difficult or on frost sensitive sites especially equipped bucket-excavators are used for making strips or piles. The new methods will likely become more expensive but might still be motivated if they can make a successful result possible.

Supply of plants: Supply of plants is a sensitive chain from the seed to the planted seedling on the planting site. Great demands are made upon cultivating the plants, distribution, storage and handling as well as upon organization and supervision. Very often the question is not to develop new knowledge but to teach and distribute old basic knowledge about plant care and planting technique through well organized education activities.

This is especially important within an area with often long storing times between the date of lifting in the climatically well situated nursery and the date of planting out. The transports are also long. In the fall there is a problem, when the plants from the "summer" climate of the nursery are not enough lignified when they set out within areas with "autumn" climate and often frosty nights. Research has shown that by means of artificial darkening and regulation of the daylength it is possible to initiate an earlier budset and termination of the growth. The method is now being introduced on a larger scale.

A number of highly industrialized plant production systems with container plants are developed and tested continuously. They vary as far as economy, technical and practical perfection, but all have the same problem—to adapt the growing status and condition of the plant to the unoptimal conditions in the forest. Today this area seems to be one of the most important.

Increasing Regeneration Costs

Compared to the logging costs, regeneration costs have been increasing significantly faster. The productivity has decreased. This trend is seriously troublesome since a large part of all silvicultural measures still consists of manual labor. A growing part of the stumpage value is needed for regeneration. If this trend cannot be broken there is both an obvious risk of a generally lower ability and ambition to invest and the danger that some areas will become impossible to utilize from a production economy point of view.

Above all, the planting is expensive. Today's methods can be somewhat more developed but the aim is to change to radically new methods. On poor sites new direct seeding methods are interesting. Automatic seeding devices which can be attached to the scarifying harrows are being tested. They continuously feed one seed per 1-2 dm (4-8 in). The present biological results are promising and it may be possible to cut the regeneration costs by 50% through this method. The bottleneck is seed supply with bad seed ripening and rare cone years.

On better sites great hopes are set on planting machines. An extensive development has been going on for more than 10 years. Planting has however turned out to be the most difficult operation by far to mechanize in the forest and we still do not have usable machines for ordinary Swedish forest land. The development is going on along two main lines: scarifying, and hole-making—planting machines and machines which are building up soil piles around the plants.

A very interesting idea is the "Hasselfors plant." A plant is produced in a compressed and plastic covered peat plate (7 x 7 cm; 3 x 3 in). The plate is with its plant placed out on exposed mineral soil and becomes firmly rooted to ground. If this method biologically fulfills its promises, entirely new possibilities are offered for both fully and partially mechanized planting systems.

Increasing Hardwood Stock

Available statistics show that in spite of active control the hardwood part of the growing stock has increased, especially in the younger stands. The reason could be bad market for hardwood timber but also low efficiency when fighting the slash vegetation on some of the clear cut areas. This trend is very serious and will in the long run create a lower total production capacity. An increase of the hardwood share of the young stands from 10-15% to 20-25% after 70 years causes about 10% less total yield. To avoid this an active use of herbicides is needed. It is not practical or economically possible to obtain the same effect with manual methods. The future of the chemical methods is, however, for a number of reasons, uncertain and restricted.

With this background the development within the sector of energy is particularly interesting. In several development projects we investigate if and how different parts of the forest biomass can be used as fuel. New markets have also opened up new possibilities for silviculture and wood production.

Shortage of Middleage Forests

In Swedish forestry a dominating problem is the shortage of middle age stands and what kind of measures and adjustments must be considered in order to reduce the coming effects of the so called "timber supply depression," Figure 4 shows the age class distribution. Of special interest are all measures that improve the yield. These shall either directly produce more timber ready to be cut when the depression comes or raise the general growth level so that the adjustment of the felling volumes can be acceptable to all parties concerned.

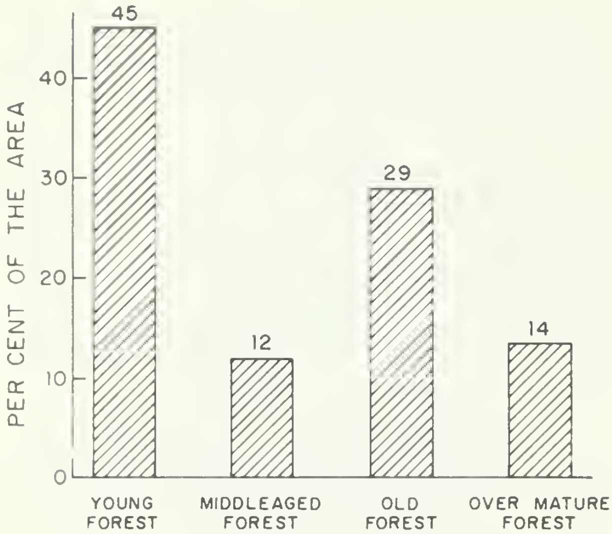


Figure 4.—Relative age class distribution of the forests. The distribution is based upon the age of each stand in relation to normal rotation period.

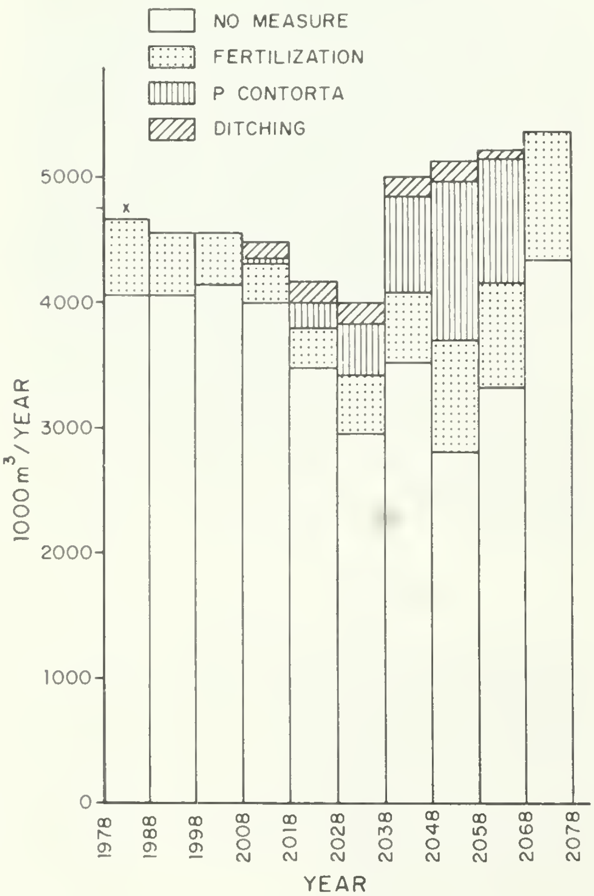


Figure 5.—Felling volumes, 1978-2070, northern Sweden.

The three most important measures which are systematically used today are planting trees and species with better growth, fertilization of stands on mineral soil, and improvement of the growth on waterlogged forest land. The measures not only make the depression more shallow but will also result in a future yield level that is higher than today's. Figure 5 shows an example from northern Sweden.

The intensive program of forest tree improvement has already been described. An increasing share of the need of seed is supplied from orchards and the new stands are expected to produce 20% more wood.

Lodgepole pine (*Pinus contorta* Dougl. ex Laud.) from the interior of British Columbia and the Yukon Territory is the only exotic species of practical value. On most sites in northern Sweden it produces 30-50% more than Scotch pine. The rotation period will be 15-25 years shorter. This gain of production must be balanced against all known and potential risks. Up until today proper provenances of lodgepole pine has not shown any severe drawbacks. One possible weakness is a more concentrated root system and therefore lower stability. During the next five years the Forest Service will plant 20% (= 8,000 hectares; 19,770 acres) of the annual regeneration area in northern Sweden with lodgepole pine.

Fertilization of mineral soils with nitrogen is also discribed above. This routine fertilization with 6-7 years intervals is an absolute precondition for the yield level and felling volume of today. Reduce fertilization immediately must be followed by reduced felling.

In northern Sweden there are large areas of peat land. Great efforts have been made to start forest production on these areas by draining and fertilization. Experience shows however that the biological and economical possibilities are very limited for most of the northern peat lands. Only the very best situated and nutritious have a good prognosis. Particularly some areas ditched in earlier periods in the lower parts of the area have a very great yield potential. Following ditching and fertilization with phosphorous and potash the whole bog is activated. Mineralization processes start which release nitrogen. The trees react immediately and a very rapid growth starts. These measures are not to a great extent expected to compete with other environmental interests since these interests mainly comprise other peat land types.

The waterlogged areas around the bogs as well as more shallow peatland where the roots of the trees can reach the mineral soil is a large hidden reserve. Here a proper ditching can raise the growth substantially and add new areas of productive forest land.

Criticism of Our Methods

It is fully evident that an active forestry influences and changes the untouched natural development of the forest. (If there exists such a thing?) Every change causes apprehension and protests. Familiar landscapes and paths are

changed. Very often it is felt that something primitive and natural is replaced by intensive timber production. Fast growing species, site preparation, herbicides, fertilization and ditching are differently looked upon by the ambitious silviculturist, wanting to grow a lot of timber for generations to come, and the Sunday wanderer who wants to pick the blueberries.

Sometimes these conflicts are real and sometimes fabricated. The critics of the large-scale growing methods of forestry have roused and/or increased strong public opinions. Sometimes these opinions have led to restrictions in the use of rational methods. Then very often the alternative has not been to use another more expensive method but to accept a lower yield ambition.

Such constant adjustments and demarcations are probably inevitable and lead to a great responsibility for the silviculturists to inform about the background, extent and consequences of different measures. It is also important that we in a professional manner take part in the debate concerning the use of the forests in the best way.

SITE PREPARATION TECHNIQUES FOR REFORESTATION

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BACKGROUND

When regenerating forests, there are two alternative methods, natural regeneration and artificial regeneration. The first mentioned method may be applied in the case of tree species producing sufficient amounts of seeds with good germinability, and on sites that become easily stocked with seedlings. It is possible to improve the regeneration with some treatment of a forest, for instance, by carrying out the final felling in a form of little openings or strips, so that the surrounding trees seed the area cut, or by leaving particular seed trees left in the area. With regard to shade bearing trees, young growth may spring up under the growing trees, if thinning is performed in an adequate way. In Finland, natural regeneration is applicable to all of the main tree species: Scotch pine (*Pinus silvestris* L.), Norway spruce (*Picea abies* [L.] Karst), and European white birch (*Betula verrucosa* Ehrh.), only. If although, it is mainly used for pine and birch only. If needed, natural regeneration can be promoted by site preparation, e.g., by breaking the humus layer.

Some tree species—especially broad-leaved trees—regenerate naturally of stump or root sprouts. Unfortunately, these kinds of trees are often of poorer quality than those grown from a seed or a seedling.

Methods used in artificial regeneration are sowing and planting, commonly called stand establishment. It is applicable both to reforesting openings after natural regeneration and to growing a new tree generation on clear cut areas. When compared with natural regeneration, forest soil cultivation offers the following advantages:

1. Seed and seedling material can be produced by certified trees, which guarantees the faster growth and better quality of wood.

2. Changing of tree species becomes possible.

3. Regeneration can be certified under circumstances, in which successful natural regeneration is uncertain (although failure of artificial regeneration cannot always be avoided, either).

4. To a certain extent, it is possible to control the growing sites and the density of trees, so that the need of plantation management and intermediate cuttings diminishes, and harvesting of thinning wood can be carried out more advantageously. It must be noted, however, that "extra seeds" often come to the regeneration area from the surrounding forests, and they produce young growth and trees not desirable.

5. In many cases, the rotation time from one final felling to another becomes shorter—in Finnish conditions usually 5-15 years.

High expenses are a disadvantage of artificial regeneration, if compared with those of natural regeneration. Thus, when choosing a reforestation method, it is necessary to consider, if the monetary advantages of artificial regeneration are greater than the costs caused by it.

As mentioned earlier, site preparation is advantageous for natural regeneration in many cases. If artificial regeneration is applied, the soil preparation of the regeneration area for this purpose is almost a basic rule.

OBJECTIVES OF SITE PREPARATION

The most important objectives of site preparation are the following:

1. Improving the capability of seedlings to compete with other vegetation. There is an effort to eliminate or at least diminish other vegetation near the growth site of a seedling, or make its growing capacity poorer.

2. Improving the growth conditions of seedlings by curing the heat economy of the ground.

3. Improving the water economy of the ground in order to advance the development of the young growth. If the ground is too wet, it is possible to drain it, or make hummocks (tilts) to be used as planting sites. If the ground is too dry, furrows or patches gathering the moisture may be considered as planting sites.

4. Changing the physical structure of the ground so that the development possibilities of the roots of seedlings become better.

5. Improving the nutritional state of the soil. The nutrient economy becomes better only, if the soil is prepared so that the humus layer rich in nutrients is mixed with mineral soil. Even if this does not happen, the seedlings growing in pure mineral soil develop better than those planted in places not prepared at all.

6. Improving the light supply to seedlings.

7. Increasing the oxygen content of growth sites.

8. Decreasing frost damages.

9. Decreasing danger of insect damages.

Regeneration areas vary considerably with regard to the soil type, moisture content of the soil, microclimate, etc. So the objectives of site preparation are different in different cases. An objective common in all the cases is, however, an effort to ensure the development of a new tree generation.

SITE PREPARATION TECHNIQUES

Broadcast burning is one of nature's own means to improve the regeneration conditions of forests. Investigations have showed that in Finland, for instance, the forests were thoroughly burnt by lightning or some other reason once every 300 years. The fire does not only improve the site for seed germination, but it also returns the health balance of a forest area (reduces damages by fungi or insects). Forest fires are nowadays relatively rare in Finland. This is due to the fact that, thanks to thinning cuts, very little dry wood is found in the forest.

As late as the 1950s, controlled broadcast burning was very commonly used in preparation of regeneration areas. After this it was almost totally given up, mainly because insurance companies no longer offered insurance for the areas to be burnt. Fire controlling techniques have very much developed within the recent years, and it seems to be obvious, that controlled burning will again be taken into use in preparation of regeneration areas.

Scarifying is an old method of soil preparation. In this method, patches for planting or sowing are scalped on the ground at pre-determined spacing. The humus layer is removed from the patches. Scarifying is applicable to soils pervious to water, but in clayey soil, for example, the patches may form water holes, in which seedlings are not able to develop. This method has been in use as early as in the times of horsedrawn equipment, and, under certain circumstances, good results have been gained. The most developed scarifiers are drawn by forest tractors, and they automatically make two rows of patches simultaneously. Scarifiers are usually equipped with two or four, 4-toothed ripping wheels, the rotation of which is stopped automatically at fixed distances with the help of hydraulic brakes. At this stage the teeth scalp the patch to the ground and turn the humus layer toward the driving direction as seen from the patch. The distance between patches is adjustable.

The power take-off of the pulling tractor must be about 30 kw, i.e., its engine power ought to be about 60 kw or more (80 HP). In recent years, this method has given way to harrowing and plowing, because these two methods prepare the site so that well-prepared sowing or planting spots are found independently of the soil type. The prices of scarifiers are more moderate than those of forest harrows or plows.

When harrowing soil (Figures 1, 2 and 3, Table 1), rather continuous furrows are formed, and the mineral soil is thus uncovered in the bottom of them. The humus soil, as well as the possible slash, are thrown to the other side of the furrow (Figure 4). The most commonly used harrows are disc trenchers, which are equipped with two or four toothed discs. In the most modern models the plowing angle and the load on the discs are hydraulically controlled by the operator in his cabin. Rolling of discs happens by a hydraulic engine connected with them. The power required for this disc hydraulic motor can be produced either by the tractor or by a separate engine. The pulling tractor

Figure 1.—TTS disc tiller.

Figure 2.—TTS disc plow.

Figure 3.—TTS disc trencher.

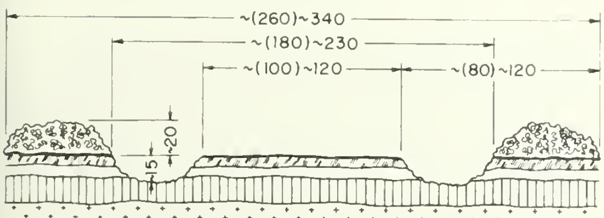

Figure 4.—Furrows made by TTS disc trencher.

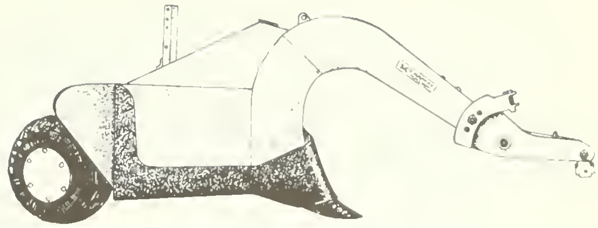

Figure 5.—Site preparation plow, Marttiini m/KLM-170

required may be either a forwarder or a skidder. The required power take-off is about 50 kw (67 HP) and the engine power about 100 kw (134 HP). There are several types of harrows for different conditions. The most modern types are provided with a special equipment for making hummocks, because the biological result has in some cases proved to be best, if seedlings are planted on a hummock.

The most efficient equipment for forest soil preparation is a reforestation plow (Figure 5). It makes a furrow, the depth of which is 20-60 cm (8-24 in), and the upper width is about 80 cm (32 in). The soil is lifted from the ditch to both sides to a distance of about 60 cm (24 in) from the edge of the furrow. So a bed of this width is left between the lifted soil and the edge of the ditch in which the mineral soil is uncovered. The tractor required is either a crawler tractor or a wheeled forest tractor with an engine

Table 1: Technical specifications of some Finnish soil preparation machines.

SCARIFIERS

Model	Length[1] cm	Width[2] cm	Height cm	Weight kg	Length of tooth cm	Diameter of drum cm	Oil volume l
Light tractor scarifier	160	45	120	260	40	56	30
m/Sinkkila	245	235	120	1,130	40	56	78

HARROWS

Model	Length cm	Width cm	Height cm	Weight kg	Length of disc spices cm	Diameter of disc cm	Furrow cm
TTS Disc Tiller	230	210	240	3,500	7	101	2x150-235
TTS Disc Trencher							
m/TTS-25	210	250	210	1,250[3]	20	82	2x80
m/TTS-35	210	300	210	1,750[4]	27	106 or 120	2x120
m/TTS-35H	230	210	240	3,000	27	106 or 120	2x150-235

PLOWS

Model	Length cm	Width cm	Height cm	Weight kg	Depth of furrow cm	Width of furrow (cm) At top	Width of furrow (cm) At bottom
Fiskars-Karhu	457	280	240	1,900	35	80	11
Marttiini							
m/KLM-170	450	170	230	1,500	25-30	50	10
m/PP-I	500	240	230	2,100	40	80	10-15
m/PP-II	470	220	230	1,900	40	60	10-15
TTS Bedding Plow[5]	320	166	145	2,000	20	75	50

[1]The length of spots: adjustable.
[2]The width of spots: 50 cm or more.
[3]With additional weight 2,500 kg.
[4]With additional weight 3,500 kg.
[5]Site preparation devices: 1 coulter and 4 discs, diameter of discs 106 cm.

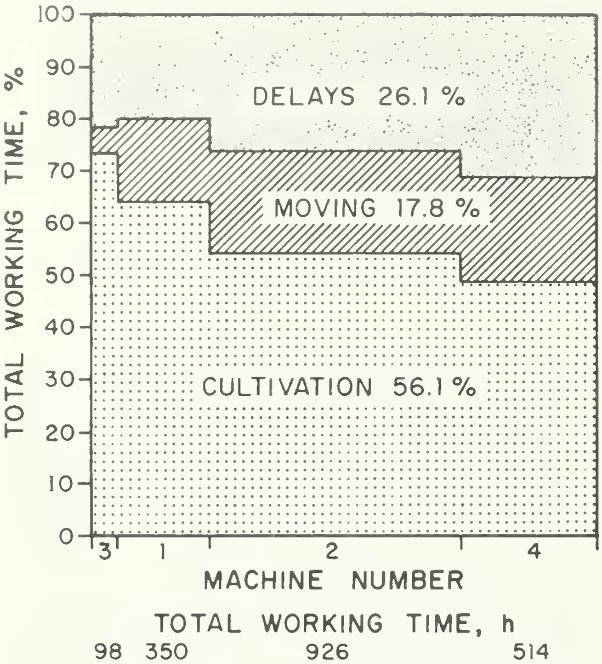

Figure 6.—Relative distribution of the total working time in harrowing. SOURCE: Kaila and Paivanen, 1978.

of at least 160 kw (215 HP). Plowing is a method used on wet sites with a thick peat layer. It may be mentioned, that the work trace of some forest harrows reminds that of plowing.

Ditching is mainly applied to draining peatland for forest growing. In Finland, for example, nearly 5 million ha (12,355,000 acres) of peatland has been drained for this purpose. Draining technique is such a wide problem, due to its nature, that it is not possible to deal with it in detail in this connection. It is worth mentioning, however, that ditches are made either with a forest ditch plow or with an excavator equipped with a shaped bucket. Rotary ditchers may also be used.

Drawing of site preparation equipment is possible on a side slope of 10% at the most. The limit of uphill slope is about 20%. If the slope is steeper, performing of soil preparation is possible only when driving downhill. In general, slopes steeper than 35% ought to be avoided for reasons.

The density of preparation traces depends on how many seedlings is wanted to be planted per unit area. In Finland, the desired number of seedlings is usually 1,400-2,800/ha (570-1,130/ac), but the most common amount planted is 2,000 seedlings/ha (800/ac). In this case the distance between prepared points (rows) ought to be about 5 meters (16 feet), if measured from the middle of them. In practice, this means driving of about 2 km/ha (.5 mi/ac).

The form of driving for soil preparation may vary according to the size and shape of the area to be prepared.

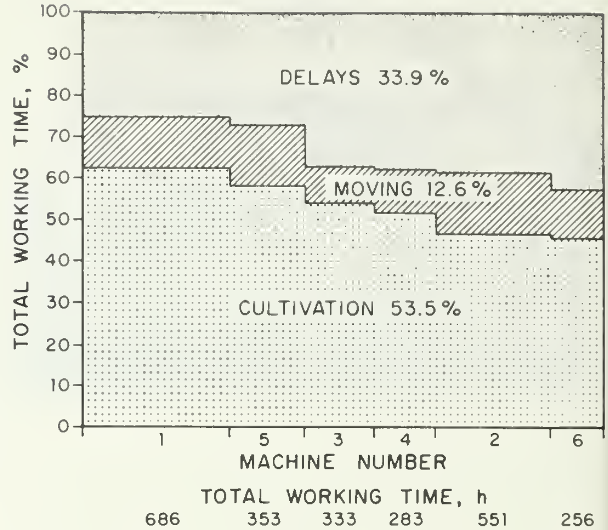

Figure 7.—Relative distribution of the total working time in wing plowing. SOURCE: Kaila and Paivanen, 1978.

If the length of the area is more than 100 m (330 ft), the usual way of driving is in the same direction, one furrow beside another. In roundish areas it is possible to "drive around" in a cricle beginning from the outer side of the area for reducing turnings. Other types of driving figures may also be used.

SOME RESULTS OF WORK STUDIES ON SITE PREPARATION

Several work studies have been carried out in the field of soil preparation in Finland (e.g. Eskelinen et al. 1976, Haarlaa 1973, Seppala 1975, Tynkkynen 1974, and Kaila and Paivanen, 1978). The following information is based on the last mentioned publication. The study dealt with six plowing units and four harrowing units. All the drawing machines were wheeled forest tractors. The relative distribution of the total working time of forest disc trenchers is presented in Figure 6 and the same for forest plows in Figure 7.

The shares of the soil preparation time were 56.1% (harrowed) and 53.5% (plows). The share of different delays was 26.1% of the total time for harrows and 33.9% for plows. The share of moving time mainly depends on the distances between the working sites, and on the quality of the route used for moving. In cases studied it was 17.8% for harrows and 12.6% for plows.

The outputs per working hour of these methods were the following:

	Average output/ha	Variation between machine units
Harrows	0.89 ha (2.20 acres)	0.76-1.03 ha/h (2.55 a/h)
Plows	0.60 ha (1.48 acres)	0.36-0.81 ha/h (2.0 a/h)

It may be found that the average output of harrows is clearly higher than that of plows. Furthermore, if the last mentioned method is used, the variation of output is greater than that of harrowing. The factors having effect on the output rate are the size and shape of the preparation area, soil type, relative slopes, amount of stones, stumps and slash, the technical construction of the machine unit, and the skill of the operator. If the size of the area is less than 2 ha, the output decreases from the average. The smaller the area is, the more the output decreases. It may be worth mentioning, that the average sizes of the regeneration sites in the studied working areas were 2.1 ha (5.2 acres) when harrowed and 3.0 ha (7.4 acres) when plowed. The irregular shape of the area also reduces the output, if the area is small.

For one harrowed unit, the following straight correlation between the preparation time (y hours) and the size of the regeneration site (x ha) was gained:

$$y = 0.26 + 0.85\,x$$

One variable explaining the lower hourly outputs of plowing is the ground. This method is usually employed on soft ground with a poor bearing capacity (peatland).

The share of preparing and service of the machines of the total delay time was 68.5% for harrowing equipment and 76.4% for plowing equipment. The share of the time that the machines were stuck was about 14% in both cases.

Moving is somewhat slower with a plow than in question of a harrow, excepting the distances shorter than 15 km (9 miles). The moving time includes the preparations, which means, e.g., removing the tracks from the bogie, and the actual time of moving. The first mentioned of these takes about 1.1 ha/case in average. The actual speed of moving (driving speed) is 8-12 km/h (6-7.5 mi/h) for distances shorter than 10 km (6 mi) and 18-21 km/h (11-13 mi/h) for distances longer than 40 km (25 mi). The dependence between the driving time of moving and the length of the distance is linear.

COMPARISONS BETWEEN DIFFERENT TECHNIQUES OF PREPARATION OF REGENERATION AREAS

Before starting of site preparation, some preparatory actions may have been taken in the area. These are called clearing of the regeneration site. In the Soviet Union, for example, slash is gathered into heaps and burnt. In Poland, at least in some cases, stumps are lifted and transported away from the area. In some other countries the slash is smashed, etc. In Finland, the slash is usually left on the area, because the danger of insect damages caused by it is small, and the soil fertilizing effect of slash, when decomposing, is regarded to be good. Furthermore, the treatment and removing of it is thought to be too expensive. If some worthless trees have been left to grow after the final cutting, they are felled, as well as bushes. If there is plenty of slash in a regeneration area, it is reasonable to wait for 1-2 years before beginning of soil preparation, so that the slash is decomposed, at least partly.

When comparing different techniques of soil preparation in regeneration areas with each other, attention must be paid at least to the following facts:

1. What kind of method is applied in possible planting? Due to the stoniness of the soil in Finland (moraine) mechanized planting may be considered only on peatlands and in afforestation of fields. The reason for this is that constructing of planting equipment for stony soils has not yet succeeded. A quite common method of planting is that of using peatpot and paperpot seedlings. In that case, a planting tube is used. Thus, the soil preparation techniques necessary for mechanical planting are only exceptionally applied.

2. Does the soil preparation trace offer different alternatives for planting so that the moisture content, permeability to water, inclination to frost, etc., of the soil can be taken into account when choosing planting spots? From this point of view, both harrowing and plowing are good methods. Harrowing is a good method especially, if the harrow is provided with an attachment for making hummocks. Instead, alternatives offered by a scarifier are few in this sense (bottom of a patch, edge, hummock lifted by a colter).

3. Does the equipment used remove the competing vegetation and slash in an area large enough? From this point of view, plowing is the best method, but harrowing is a good one, too. The question also refers to the number of alternative planting spots.

4. Is the method applicable in different soil and terrain conditions so that many types of soil preparation equipment are not needed? From this point of view, harrows are the most versatile of the machines mentioned.

5. What are the costs of the equipment per output unit (for example, ha)? Scarifying is the cheapest and plowing the most expensive of the alternative methods mentioned. The most important objective is, however, the successful stand establishment, and, from this point of view, the differences in output costs per unit are insignificant.

Generally speaking, it may be said that harrowing applies to almost or quite dry mineral soils, and on moldery and stony upland forest soils with grass-herb vegetation. The objectives of plowing are loosening of the soil, diminishing the moisture of the surface layer and raising the temperature of the soil, and so it is applicable to fresh and solid or fine-textureed mineral soils, and, as so called tilt-plowing, on water-logged soils with a thick raw humus layer. Making hummocks may be combined with peatland drainage when an excavator is used. A condition of controlled burning is a good water supply. This method covers both clearing and preparation of a regeneration area, and is applicable to areas with a thick raw humus layer and to stony soils, especially if there is plenty of slash or the area is damaged by the fungus *Fomes annosus*.

TERRAIN CHARACTERISTICS FOR SITE PREPARATION

The Nordic countries have worked in cooperation in order to develop a classification system applicable to all the operations of forestry, including the stand establishment (Eriksson, Nilsson and Skramo, 1978). The problem of forest classification is very complicated, because, in practice, there is an unlimited number of different combinations of terrain factors to be found. In this connection, it is impossible to deal with this wide problem except referring to some main principles.

The first thing to note is that the need of classifying the terrain consists of two stages. The first one is the description and classification of the terrain as it is. This classification, called a primary classification system, preserves its validity in time, because most of the terrain factors are stable and very slowly changing. The second stage is called either secondary or operational classification. The problem dealt with at this stage is the relation between different terrain classes and different operations carried out in the terrain, like terrain transport, forest soil preparation, forest road construction, etc. This classification must be transformed every now and then, when essential changes of operation techniques take place. In practical working life, the second stage is the one mainly needed. In case of soil preparation, for instance, information is needed about the dependence of the output, costs, quality of the work trace, etc., on the variation of the terrain.

The basic factors of the classification are the following:

1. Ground conditions and soil types
2. Ground roughness
3. Slope conditions.

The completing factors are:

1. Stoniness of the ground surface
2. Humus layer and ground vegetation
3. Slash and stumps.

Both basic and completing factors are described using a scale of 1-5, where 1 indicates the best conditions and 5 the most difficult ones. For defining the different factors in the field, field work instructions have been written (Nilsson 1979). The final class is reached as a result of counting by points.

CONCLUSIONS

It seems to be obvious that artificial regeneration all the more replaces natural regeneration in Finland. Nowadays the area regenerated annually is about 100,000 hectares (247,100 acres). How applicable the Finnish site preparation techniques are in the conditions of Alaska, is a question impossible to be answered at first glance. However, our methods might offer a useful starting point to experimental actions, if some are regarded worth starting.

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SOME PRACTICAL METHODS FOR SECURING ADEQUATE POSTCUT FOREST REPRODUCTION IN CANADA

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THE FOREST RESOURCE

Canada's forest land occupies an area of 3,417,000 km^2 (1,319,300 mi^2), which is about 37% of the nation's total land area (9,218,000 km^2 [3,559,000 mi^2]), nearly 4.7 times the area of agricultural land (730,000 km^2 [281,800 mi^2]), and second only to the combined area of tundra, barrens, alpines, and other similar wildlands (4,334,000 km^2 [1,673,400 mi^2]). About 3,141,000 km^2 (1,212,700 mi^2) of the forest land are classified as an unreserved production land that can be used for growing timber. However, only 1,984,000 km^2 (766,000 mi^2) of the production land are inventoried as currently productive forest land, of which 1,611,000 km^2 (622,000 mi^2) are economically accessible (Bowen 1978).

The wood volume of the productive and economically accessible forest land is estimated at 17,229,000,000 m^3 60,835,599,000 ft^3) (Bowen 1978). About 80% of this wood volume is in softwoods, with the most abundant species being black spruce (*Picea mariana* [Mill.] BSP.), white spruce (*Picea glauca* [Moench] Voss), jack pine *Pinus banksiana* Lamb.), lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.), balsam fir (*Abies balsamea* [L.] Mill.), eastern hemlock (*Tsuga canadensis* [L.] Carr.), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), eastern white cedar (*Thuja occidentalis* L.), western red cedar *Thuja plicata* Donn), and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco). The remaining 20% of the wood volume is in hardwoods, with poplar species (*Populus tremuloides* Michx. plus some *Populus balsamifera* L.) and white birch (*Betula papyrifera* Marsh.) predominating Cayford and Bickerstaff 1968; Bowen 1978).

As calculated for the area south of 60° N latitude, where in fact most of Canada's forests are located, the nnual allowable cut and the average annual timber harvest re 256,305,000 m^3 (9,050,129,600 ft^3) and 156,383,000 m^3 (5,521, 883,700 ft^3), respectively, leaving some 9,922,000 m^3 (3,529,245,800 ft^3) in reserve. The implied vailability of this reserve, however, is somewhat deceiving ecause about 43% of the wood volume that remains unut is economically inaccessible. Moreover, timber deficits egin to occur at a more localized level, and softwood upply problems are on the increase (Reed et al. 1978a; Newnham 1978).

THE STATE OF FOREST REGENERATION

Although Canada is still one of the world's leading forest nations, there is an increasing general apprehension that this favorable position may be lost in the not-too-distant future unless substantial improvements are made right now in the overall reforestation of problem cutovers and other fail areas. The backlog of such areas, variously estimated in excess of 44,515 km^2 (17,190 mi^2), is increasing at an average annual rate of about 2,728 km^2 (1,053 mi^2). Roughly 56% of this increase is attributable to regeneration deficiency after harvest cutting, and a further 44% is attributable to other causes such as insect and disease infestations or the occurrence of certain types of wildfire. It is estimated roughly that about 20% of the total annual harvest area fails to regenerate adequately to the desired tree species, while the remaining 80% of such area regenerates at an acceptable level either by unaided means such as natural seeding, resprouting, etc., or through the use of mechanical scarification, controlled burning, planting, direct seeding, etc. in various combinations (Paille 1977).

Most of the productive forest land in Canada is under provincial jurisdiction (87%) (Bowen 1978), and practically all primary wood-processing industries within such lands operate on the basis of long-term leases. This arrangement is often severely criticized because it seldom results in the practice of proper land management, including the very fundamental task of forest regeneration. Some provincial forest services are doing better jobs of managing their lands than are the others, but still there is not even one provincial organization that can claim consistently adequate forest regeneration following any kind of disturbance, and this includes harvest cutting (Reed et al. 1978a; Newnham 1978). As for the federally (6%) and the privately (8%) owned productive forest land (Bowen 1978), the overall managerial performance in both these cases is not better than that on the provincial land. In only one or two instances, the privately owned land appears to be managed at an acceptable level. However, the provinces, the private sector, and the federal government departments now are beginning to recognize the urgent need for more intensive management, including work on forest regeneration (Reed et al. 1978a, 1978b; Newnham 1978). Let us hope that the participants involved will agree soon on the proper funding necessary for effective implementation of the intended programs.

MAJOR CAUSES OF REGENERATION FAILURE

Many softwood species fail to regenerate adequately after harvest cutting mainly because most of the loose, surface forest-floor materials remain undisturbed. The surface materials, consisting often of feather moss (*Pleurozium schreberi* [Brid.] Mitt. occasionally with some *Hylocomium splendens* [Hedw.] B.S.G. and *Ptilium crista-castrensis* [Hedw.] De Not.) and foliar litter that merge downward into either an upland mor or a lowland peat, are subject to rapid losses of moisture when exposed to increased solar radiation and ventilation. This alone makes them extremely poor media for seed germination and seedling survival. Moreover, the overshading created by logging slash and the often severe competition from deciduous vegetation can further hinder the re-establishment of softwoods after cutting. These conditions can be rectified, however, by either mechanical scarification or controlled burning, with provisions for subsequent planting or seeding.

The regeneration failures may also occur when, in absence of marginal seed sources, wildfires destroy young softwood stands or they burn through softwood clear-cut areas. In both instances, prompt replanting or reseeding is required before plant competition becomes too severe.

Adequate protection from insects, disease, and mammals must be provided under all circumstances to minimize the regeneration losses. Occasionally, the losses may lead to total devastation in the absence of such protection.

Among the hardwoods, poplar species regenerate very well after cutting, mainly through root suckering, and they usually become a hindrance to the reproduction of softwoods. Most other hardwoods encounter practically the same difficulties as the softwoods in reproducing themselves after cutting.

MAJOR REMEDIAL TREATMENTS

Ideally, a regeneration plan is formulated well in advance of timber harvesting. The first prerequisite is that the plan must be based on a thorough evaluation of the forest ecosystem under consideration, with particular attention given to its productive capacity (wood volume per unit area, or tree height/age relationships), its soil (type and depth of organic overburden, texture, structure, petrography and depth of mineral materials, position of water table, and long-term moisture regime), its topographic position and microclimate, and its successional tendency in terms of vegetation changes after disturbance. The regeneration plan is then to include specifications pertaining to the type and season of harvest cutting plus the types and sequence of silvicultural treatments needed—all in view of the preselected tree species that best fit the anticipated environmental conditions.

Throughout Canada, clear-cutting is the most common method of harvesting softwood timber, although cutting in a strip-like fashion is slowly gaining popularity under some conditions. In mixed stands, selection cuts are often practiced, but only to the extent that the more valuable individuals are removed while the others are left standing. The use of seed-tree systems is restricted to a few isolated instances.

Good records of treatment costs and results in terms of regeneration are extremely beneficial, because they aid in planning future operations. However, a knowledge of the costs alone verifies the expenditures and nothing else. It may cost, for example, about twice as much to scarify and plant than to scarify and seed (Waldron 1973). Scarification costs alone can be somewhat less than one-third the total cost of scarification plus planting and somewhat more than one-half the total cost of scarification plus seeding (Richardson 1973). Moreover, the cost of burning can be about one-third or less the cost of scarification. In short, none of this shows how much really can be accomplished by manipulating the treatments according to the costs unless one has reliable data on the conditions of the resulting young stands some 10 years or more after the treatments. Unfortunately, very few data of this kind are currently available, and results of much shorter duration will have to be used in selecting treatment combinations.

Mechanical Scarification

In practice, scarification includes all degrees of mineral soil exposure, from very minimal to extreme. It is designated to improve the conditions for either planting or seeding. The exposure may be at random with considerable intermixing of organic materials, in parallel furrows, or in uniformly spaced scalps. Among the equipment currently used are: (1) diverse bulldozer blades, multiple disks, drums, and anchor chains for more or less random scarification; (2) plows, rippers, and disk trenchers for scarification in furrows; and (3) various spot cultivators for scarification in scalps (Cayford et al. 1967; Cayford and Bickerstaff 1968; Hellum 1973; Richardson 1973; Rudolf 1973; Waldron 1973; Norman 1978). The use of anchor chains for simultaneous scarification and slash redistribution on jack pine sites soon after cutting usually results in good regeneration without additional treatments (Ball 1975). The seed in this instance is released from cones in slash by the heat of solar radiation.

Controlled Burning

The use of burning for silvicultural purposes is proving to be of considerable value. A controlled fire usually burns the slash, aerial parts of vegetation, surface moss and litter, and depending on site and weather, varying quantities of th underlying mor or peat. The organic materials remaining after the fire normally include charred stumps and other large pieces of wood, partially burned mor or peat and unburned plant roots in such mor or peat. These conditions are usually adequate for planting softwoods, and if the fire burns deep enough into the mor or peat, they can be favorable also for the reproduction of softwood by seeding. However, complete burning of the forest-floor materials is neither required nor desirable. The best fire-produced seed-

beds on moderately dry to moderately moist upland sites are in those situations where exposed mineral soil and thin residual mor alternate, and both have uniform areal distribution. Deeper mors and lowland peats, which normally occur on moist to very moist sites, become favorable seedbeds as soon as the fire burns off the loose, surface moss and litter. Means of selecting the proper conditions for burning the desired amounts of mor or peat are already available (Chrosciewicz 1959, 1967, 1968, 1974, 1976, 1978a, 1978b, 1978c).

Planting

Nearly all regeneration programs involve planting bare-root stock, and the most common practice is to plant by hand using the slit method (Cayford and Bickerstaff 1968). Poor tree survival in some of the older plantations is attributable to excessive plant competition and deficient site preparation. However, survival substantially improves when the planting follows mechanical scarification or plowing. The results are also generally better when the stock is planted early in spring instead of in the fall (Froning 1972). Planting the bare-root stock on controlled-burn sites normally leads to good tree survival and good rates of growth (Chrosciewicz 1978d). The common occurrence of "J-roots" (Van Eerden 1978) can be eliminated by proper positioning of the transplants when the slit method is used.

After years of experimentation with various container-grown stock, it appears now that the provision of vertical ribs within both the BC/CFS styroblocks and the Spencer-Lemaire root trainers (Carlson 1979) should solve the problem of major root deformities such as spiralling and kinking (Johnson and Walker 1976; Carlson and Nairn 1977). Both of these containers are used to produce "plugs" that are outplanted in the field without the containers.

Direct Seeding

This operation may involve spot seeding with special cultivators that automatically release a few seeds on each scarified scalp. It may be done as row seeding by using some other devices that space the seeds evenly along the plowed furrows. In addition, standard cyclone seeders may be used in some situations where postscarification broadcast seeding is the objective; this can be carried out by covering the ground on foot, by snowmobile, or by aircraft. Because the amount of seed sown and the season of seeding vary considerably from operation to operation and from species to species, the results are extremely erratic. Understocking seems to be the most frequent problem, although when a seeding operation is successful there may be a problem of overcrowding. Density adjustments, either by filling in the regeneration gaps or by thinning the overcrowding when it occurs, often are required following direct seeding (Hellum 1973; Richardson 1973; Rudolf 1973; Waldron 1973). Spring broadcast seeding on controlled-burn sites usually results in successful regeneration, in terms of both adequate stocking and rapid growth (Chrosciewicz 1970, 1974, 1978d). Indications are that with improvements in timing and application, direct seeding can become a very useful alternative to planting.

Seed-Tree Systems

Generally, very little work is being done using this method, although controlled burning under seed trees is usually highly successful in terms of forest regeneration (Chrosciewicz 1959, 1976, 1978d). The seed-tree method, however, is applicable primarily to the tree species such as jack pine, lodgepole pine, and to some degree black spruce that develop and store large quantities of seed in tightly closed cones. When fire burns underneath, the heat triggers cone opening and thus aids in seed dispersal. Other species such as white spruce, for example, do not possess this capacity but develop and freely disperse their seed at irregular intervals. This differentiation in both production and storage of seed must be considered when the use of seed-tree systems is contemplated.

FUTURE RESEARCH

In conclusion, this brief overview shows that there is a considerable body of knowledge in the field of forest regeneration, but it has to be better utilized for the site-specific needs that may arise. The time of intensive forest management is not too far away, and we must be prepared through research to take a meaningful part in its implementation.

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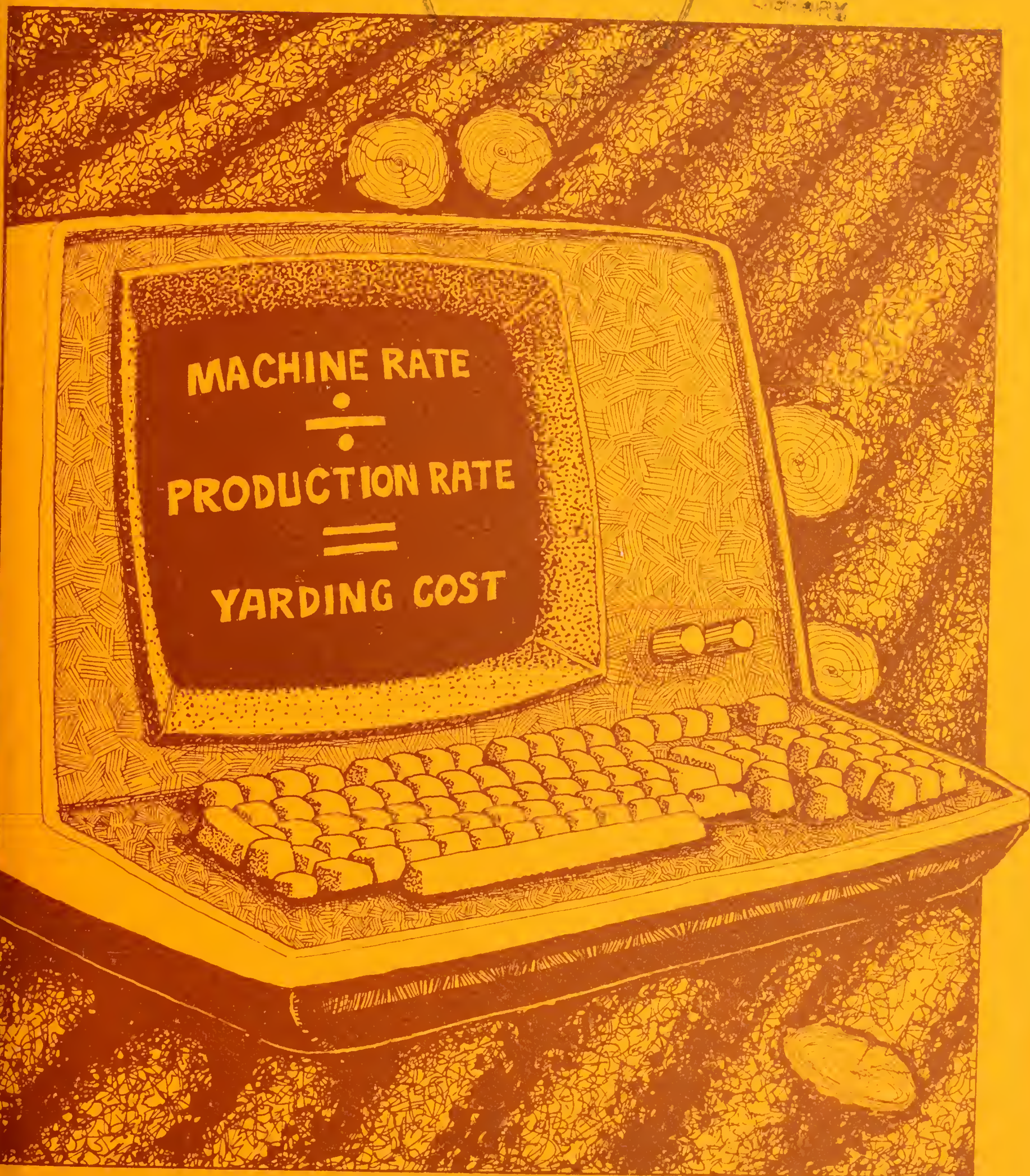
Computer Assisted Yarding Cost Analysis

Ronald W. Mifflin



Abstract

Programs for a programable calculator and a desk-top computer a provided for quickly determining yarding cost and comparing the economics of alternative yarding systems. The programs emphasize the importance of the relationship between production rate and machine rate, which is the hourly cost of owning and operating yarding equipment. In addition to generating the data required f analyzing the cost of a yarding operation, the desk-top program plots the yarding cost versus production rate curve. Examples an simple step-by-step operating procedures are included.

Metric Equivalents

1 acre = 0.4047 hectare
1 gallon = 3.785 liters
1 foot = 0.3048 meter

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Contents

ıtroduction

Good logging planning is characterized by a systematic evaluation of alternatives and selection of the yarding system that best meets environmental and silviculture criteria for the least cost. Comprehensive cost analysis is needed in the planning stage to compare acceptable yarding systems.

This report presents programs for a programable calculator and a desk-top computer for determining yarding cost and comparing alternative yarding systems. Both programs are based on the yarding cost structure given by Mifflin and Lysons (1978)[1]. Cost formulation is automated to enable the planner to quickly compare alternatives.

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Selecting low priced equipment to reduce yarding cost may not be the solution to economical yarding. Although equipment prices are high, the cost of owning the equipment is generally overshadowed by operating costs. Ownership and operating costs, when combined and expressed on an hourly basis, make up the machine rate. Mifflin and Lysons (1978)(see footnote 1) presented the breakdown of the cost components which make up machine rate (see figure 1). Production rate is often a more critical factor in determining yarding cost and is generally the most difficult aspect of yarding to predict. Production rate is defined as the volume of timber brought to the landing per unit of time. The cost of road changes (moving the yarder and rigging the lines) and the cost of moving the equipment in and out also affect the yarding cost.

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[1]Mifflin, Ronald W., and Hilton H. Lysons. 1978. Skyline yarding cost estimating guide. USDA For. Serv. Res. Note PNW-325, 19 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

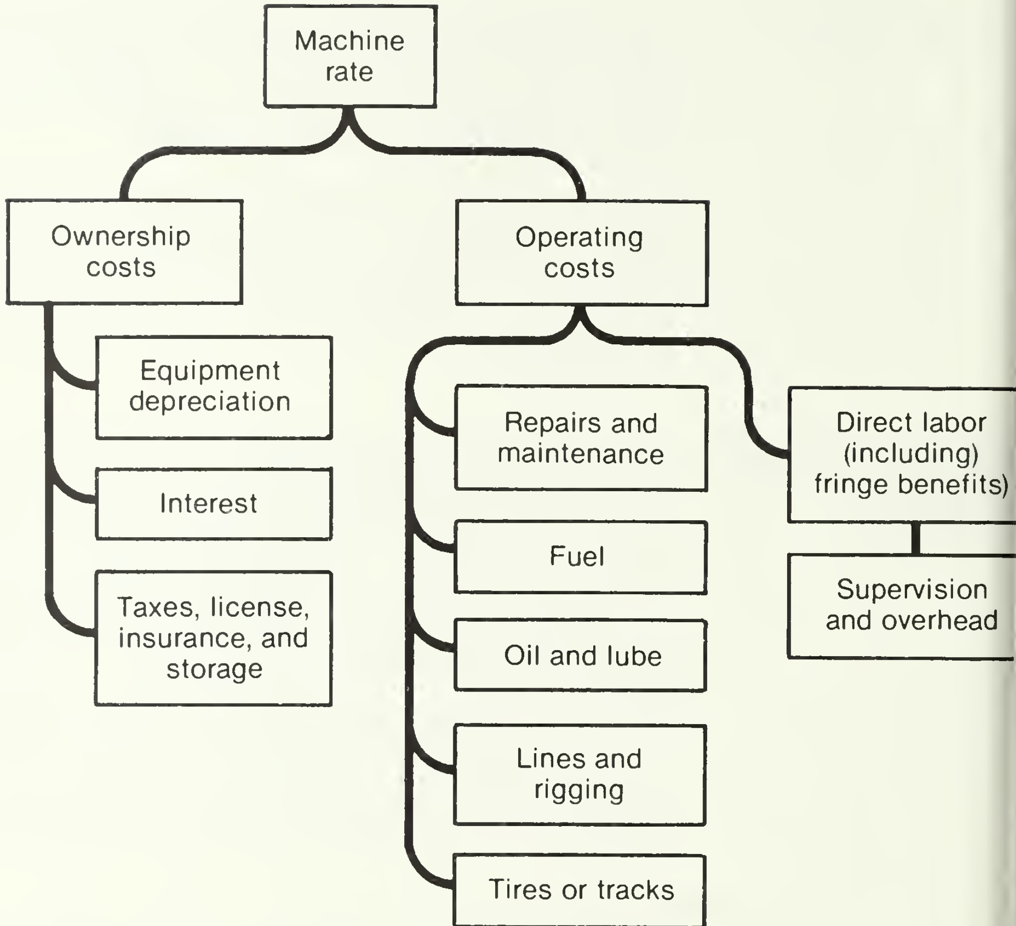


Figure 1.--Machine rate cost elements.

The yarding cost equation is expressed as

$$\text{YARDING COST (\$/UNIT VOLUME)} = \frac{\text{MACHINE RATE (\$/HOUR)}}{\text{PRODUCTION RATE (VOLUME/HOUR)}}$$

$$+ \frac{\text{MACHINE RATE (\$/HOUR)} \times \text{TOTAL ROAD CHANGE TIME (HOURS)}}{\text{TOTAL AREA (ACRES)} \times \text{YIELD (VOLUME/ACRE)}}$$

$$+ \frac{\text{MOVE IN AND MOVE OUT COST}}{\text{TOTAL AREA (ACRES)} \times \text{YIELD (VOLUME/ACRE)}} .$$

The importance of the yarding cost equation is shown in figure 2 The curve is the plot of the equation for a given, constant mach rate.

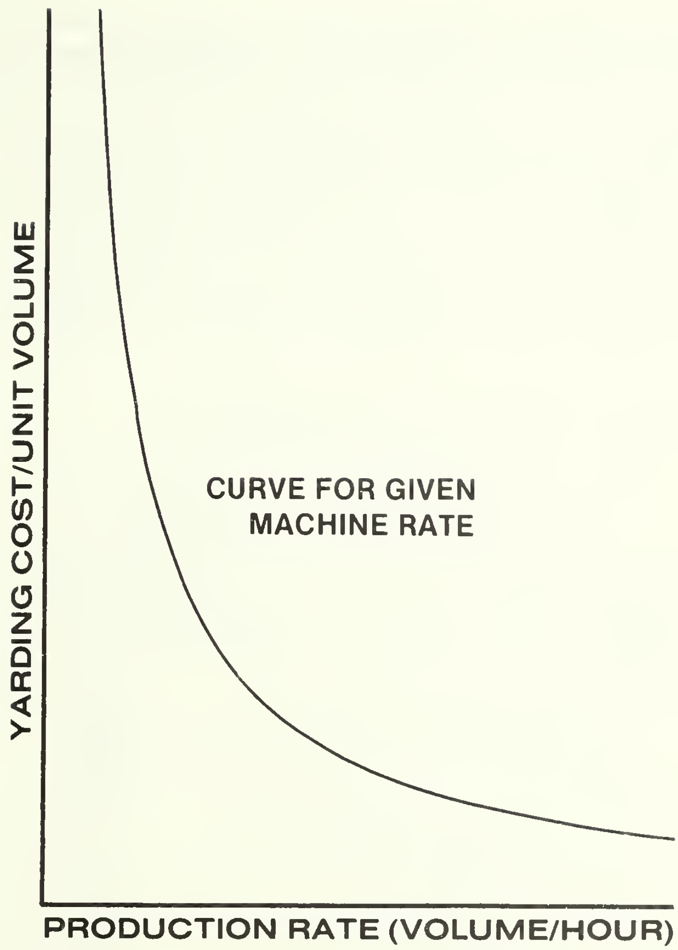


Figure 2.--Yarding cost versus production rate.

The most significant feature of the curve is the sensitivity of yarding cost to changes in production rate. Production rate can be expressed algebraically as follows:

PRODUCTION RATE = AVERAGE LOG VOLUME X LOGS PER TURN X TURNS PER HOUR.

The average number of logs per turn tends to be constant for a system, and is usually determined by the ability to gather scattered logs into a turn. The number of turns per hour is primarily dependent on machine design for a given yarding application. Log volume is therefore the most influential element in the production rate equation. Thus, in figure 2 the lower production rate generally denotes small logs; and the higher rate, or right-hand portion of the curve, denotes larger logs. With the inherently low production rate for small logs, yarding cost is highly sensitive to minor production rate variations due to the steepness of the curve.

The time spent operating in the woods is defined as operating ti
Figure 3 shows the components which make up operating time. Productive time is the portion in which yarding takes place; that i
the cycle time. The fixed time elements are normally constant fo
a particular yarding system on a per setting basis. Hooking and unhooking chokers are independent of yarding distance. The inhau
and outhaul of chokers are directly related to yarding distance and are therefore variable times. Nonproductive time includes ro
change time (rigging and moving to a new yarding road), move in and move out time, and delay time. No yarding takes place during these times. The following example illustrates the cost sensitiv

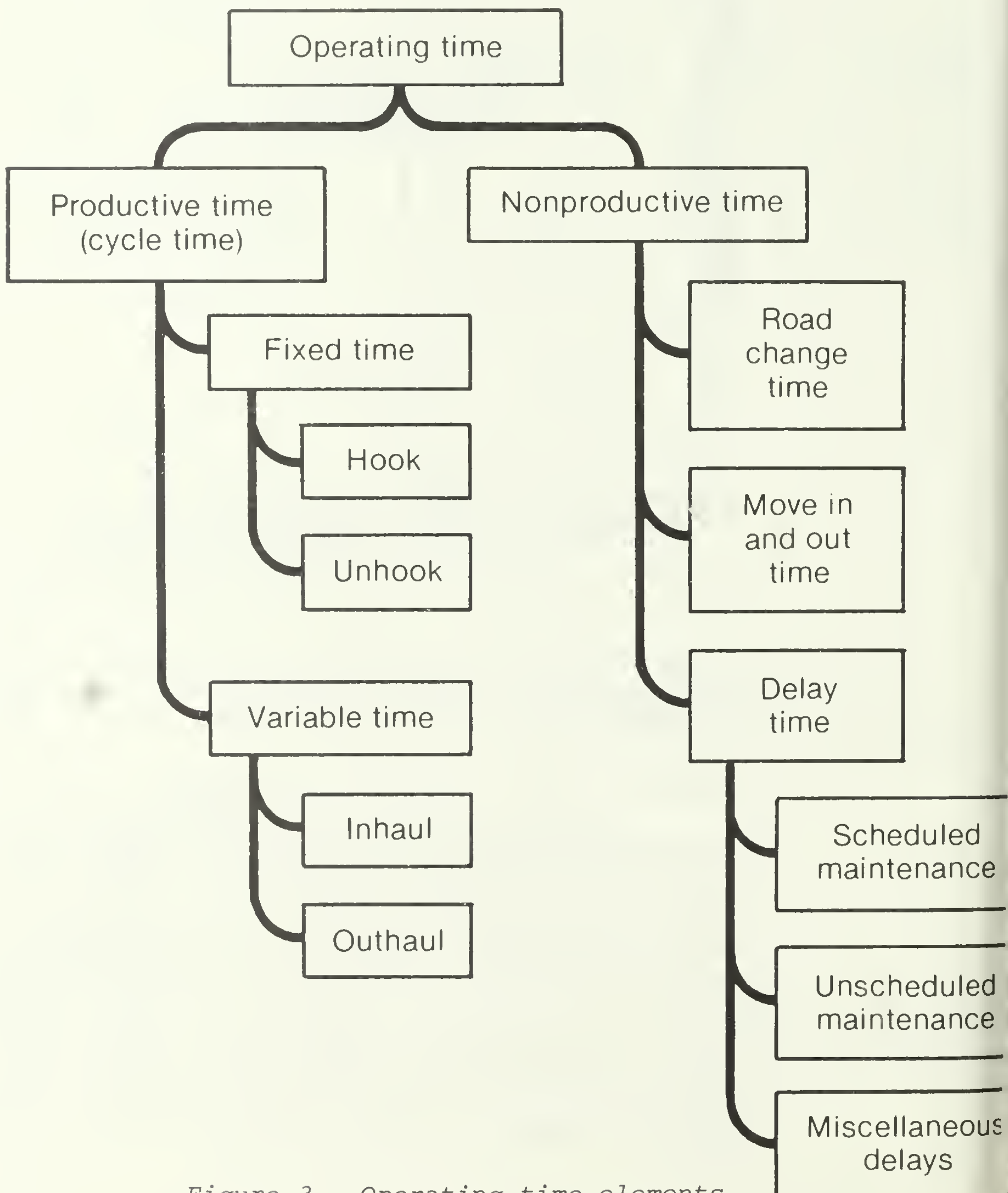


Figure 3.--Operating time elements.

of small-log harvesting and the usefulness of making a detailed cost analysis when comparing alternative yarding systems.

Two small-log yarding systems for use in thinning operations are compared on the basis of cost. Both systems employ skyline yarders operated by a crew of three. Cost and production data are estimated for both yarders and detailed in table 1. The equipment investment for System 1 is $70,000. System 2 equipment is valued at $140,000. The machine rates are $65.59 for System 1 and $79.13 for System 2. Thus, a 100-percent increase in equipment cost results in machine rate increase of only 21 percent.

It is assumed that added design features of the System 2 yarder lower its yarding cycle time and reduce delays. This raises productivity by increasing turns per hour. The production rate for System 2 is 3.5 cunits[2]/hour compared to 2.1 cunits/hour achieved with System 1. Log volume is assumed to be 10 cubic feet (0.1 cunit), and turn size averages 3.5 logs per turn for both systems. The difference in production rate is due to the number of turns per hour; 10 for System 2 and 6 for System 1.

The gain in production rate for System 2 is achieved at the expense of doubling the cost of equipment. On a cost per unit volume basis, however, the cost saving is significant. The yarding cost for System 2 is $24.54/cunit, a 26-percent decrease from the $33.08/cunit cost for System 1. The plot of the yarding cost equation in figure 4 illustrates this situation.

---

[2]A cunit is a unit of volume measuring 100 cubic feet.

Table 1--Example cost and production data

Item	Unit	System 1	System 2
Equipment cost	Dollars	70,000	140,000
Residual	Percent equipment cost	20	20
Depreciation period	Years	7	7
Repairs and maintenance	Percent equipment depreciation	50	50
Annual interest rate	Percent	12	12
Tax, license, insurance, and storage	Percent	9	9
Operating season	Days worked/year	200	200
Operating time per day	Hours	8	8
Fuel consumption	Gallons/hour	2	2
Fuel cost	Dollars/gallon	.80	.80
Oil and lube	Percent fuel consumption	5	5
Oil and lube cost	Dollars/gallon	1.50	1.50
Line cost	Dollars	3,600	3,600
Line life	Hours	1600	1600
Rigging cost	Dollars	1,000	1,000
Rigging life	Hours	800	800
Tire or track replacement cost	Dollars	0	0
Total crew wage	Dollars/hour	30	30
Fringe benefits	Percent total crew wage	30	30
Travel time per day	Hours	0	0
Supervision and overhead	Percent direct labor	20	20
Cutting unit area	Acres	35	35
Yield per acre	Cunits	40	40
Average volume per piece as bucked	Cunits	0.1	0.1
Average number of pieces per turn		3.5	3.5
Average number of turns per hour		6	10
Number of yarding roads in unit		10	10
Time per road change	Hours	1	1
Move in and move out cost	Dollars	2,000	2,000
Ownership cost	Dollars/hour	11.04	22.08
Operating cost	Dollars/hour	54.55	1/57.05
Machine rate	Dollars/hour	65.59	79.13
Production rate	Cunit/hour	2.1	3.5
Road change cost	Dollars/cunit	0.42	0.51
Move in and move out cost	Dollars/cunit	1.43	1.43
Yarding cost	Dollars/cunit	33.08	24.54

1/The operating costs for the two systems would be equal except that repairs and maintenance cost (a part of operating cost) increases proportionately with an increase in equipment cost.

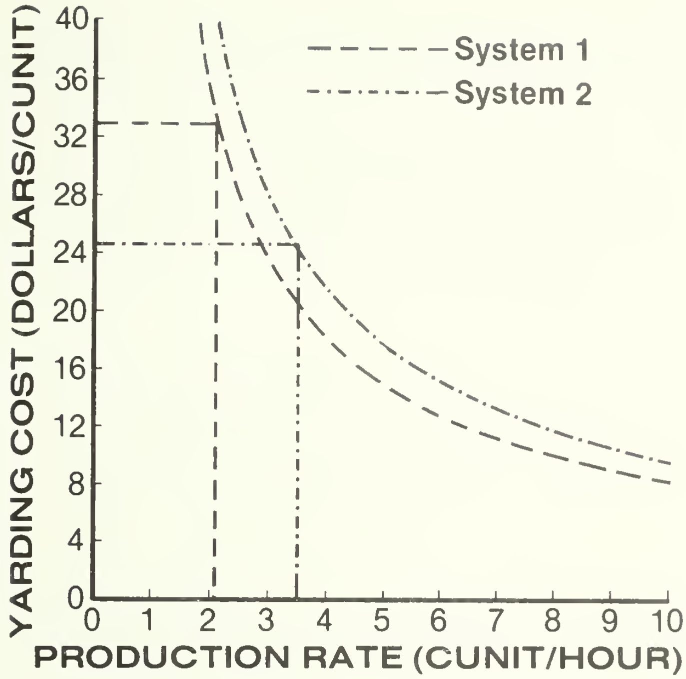


Figure 4.--Yarding cost versus production rate curves for System 1 and System 2.

pplication

The programable calculator and desk-top computer programs require inputs relating to ownership cost, operating cost, cruise data, and production rate estimates. These values are entered in a format based on the worksheets developed by Mifflin and Lysons (1978) (see footnote 1). The programs compute yarding cost and production rate using data initially entered as base values. These can be changed and the results of these new values compared to the base values.

The desk-top computer program supplies printed output not available on the calculator. Input values and results are documented. The desk-top program also plots curves to help the planner visualize the sensitivity of the relationship between yarding cost and production rate (figure 4).

The desk-top program, although it may appear complicated or lengthy, is a straight-forward, step-by-step method for determining machine rate and yarding cost. Once that is done, a number of optional steps may be taken to produce a more detailed yarding system cost analysis. The basic functions of the program are shown in figure 5.

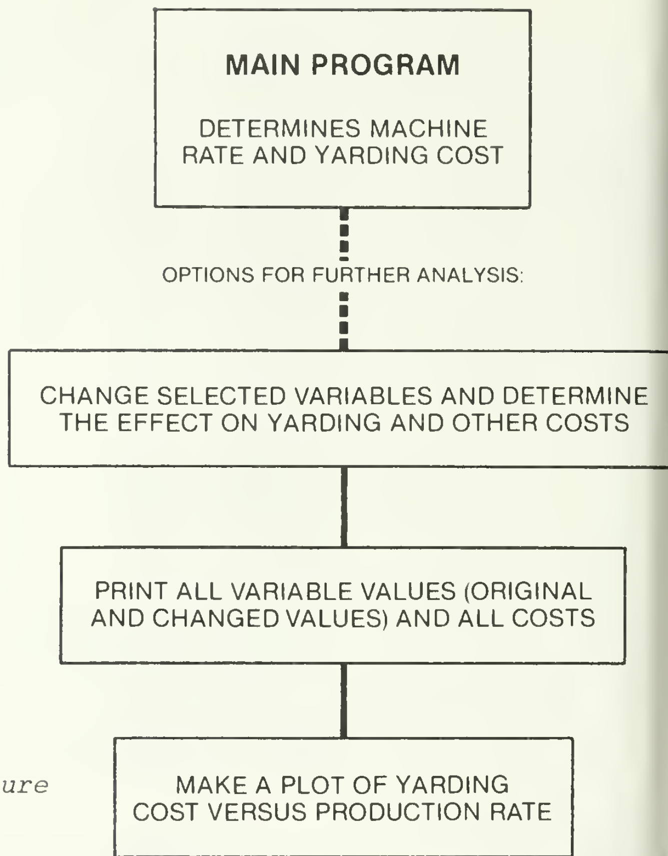


Figure 5.--Basic structure of desk-top computer program.

User's Guide

Operating instructions and program listings are given for a programable calculator and a desk-top computer system. They were developed on, but not limited for use on, a Hewlett-Packard 97[3] or 67 calculator and a 9845A or 9845B desk-top computer using ASCII BASIC language. The desk-top system requires a minimum internal memory capacity of 50,000 bytes. Certain output may be generated on a peripheral plotting device if available, as well a on the CRT screen or internal printer. The program was developed to use the Hewlett-Packard 9872A plotter.

[3]Mention of trade names does not constitute endorsement by the USDA Forest Service over other brands that can do equivalent functions.

Operation of Programable Calculator Program

The following procedures presume a knowledge of the Hewlett-Packard 97/67 or 9845A/B system operation. Only instructions pertaining to the use of these programs will be provided.

The inputs to this program are similar to the worksheets developed by Mifflin and Lysons (1978)(see footnote 1) for determining machine rate, production rate, and yarding cost. The program provides a faster means of computing the same values that can be derived by hand using the worksheets.

General Information

1. This program is comprised of three sections. The first computes ownership cost and is entered through key A. The second computes operating cost and is entered through key C. The third calculates production rates and yarding costs and is entered through key D or key E.

2. Only one piece of equipment at a time may be entered, unlike the desk-top computer program which allows up to nine pieces to be analyzed simultaneously.

3. Values for all variables must be entered. If variables are not applicable or are zero, they must be entered as zero.

4. If a mistake is made while entering values, either continue on through the section and then start the section over, or press "GTO" then ".001," and start the section over.

5. If you desire to change one or more variables in a section, the variables for the entire section must be re-entered. Also, if Section I is redone, Section II must also be redone. Section II or Section III, however, can be redone alone.

6. Certain machine or production values may be accessed during or after program completion. Table 2 shows what values are stored and where they reside. Values are displayed by pressing "RCL," the recall key, then the appropriate storage register key (A, B, C, D, E or 0-9).

Table 2--Storage register values

Storage register	Value displayed after completion of Section:		
	I	II	III
A	residual value	residual value	residual value
B	equipment depreciation	equipment depreciation	equipment depreciation
C	average annual investment	average annual investment	average annual investment
D	hours worked per day	hours worked per day	hours worked per day
E	hours worked per year	hours worked per year	hours worked per year
0	taxes, license, insurance, and storage cost	taxes, license, insurance, and storage cost	taxes, license, insurance, and storage cost
1	ownership cost (dollars/hour)	ownership cost (dollars/hour)	ownership cost (dollars/hour)
2		operating cost (dollars/hour)	operating cost (dollars/hour)
3		machine rate (dollars/hour)	machine rate (dollars/hour)
4		supervision and overhead (percent)	gross production rate (volume/hour)
5		fuel consumed (gallons/hour)	gross road change cost (dollars/unit volume)
6	depreciable value	depreciable value	gross move in and move out cost (dollars/unit volume)
7	depreciation period	depreciation period	gross yarding cost (dollars/unit volume)
8			(100-percent defect)/100
9			net yarding cost (dollars/unit volume)

Operating Procedures

1. Set calculator to "run" and "manual" modes.

2. Insert sides 1 and 2 of program card. Display will read 0.00.

A sample response is shown in parentheses following each step. Sample output is shown following all input steps. The relationship between program input and use of the worksheets can be seen by comparing the inputs (shown in parentheses) with the bold-faced values entered on the worksheets, pages 14 through 17.

Section I. Ownership Cost

1. Key in: Equipment cost, press ENTER↑ (140000)
   Key in: Residual (percent of equipment cost), press ENTER↑ (20)
   Key in: Depreciation period (years), press A (7)
   Display: equipment depreciation (dollars/year) 16000.00

2.	Key in:	Annual interest rate (percent), press ENTER↑	(12)
	Key in:	Taxes, license, insurance, and storage (percent of average annual investment), press ENTER↑	(9)
	Key in:	Operating season (days worked/year), press ENTER↑	(200)
	Key in:	Operating time per day (hours), press A	(8)
		Display and print: ownership cost, dollars/hour	22.08

Section II. Operating Cost

1.	Key in:	Repairs and maintenance cost (percent of equipment depreciation), press ENTER↑	(50)
	Key in:	Fuel consumption (gallons/hour), press ENTER↑	(2)
	Key in:	Fuel cost (dollar/gallon), press C	(.80)
		Display: repairs and maintenance cost, dollars/hour	5.00
2.	Key in:	Oil and lube (percent of fuel consumption), press ENTER↑	(5)
	Key in:	Oil and lube cost (dollars/gallon), press ENTER↑	(1.50)
	Key in:	Line cost, press ENTER↑	(3600)
	Key in:	Line life (hours), press C	(1600)
		Display: oil and lube cost, dollars/hour	0.15
3.	Key in:	Rigging cost, press ENTER↑	(1000)
	Key in:	Rigging life (hours), press ENTER↑	(800)
	Key in:	Tire or track replacement cost, press ENTER↑	(0)
	Key in:	Tire or track life (hours), press C	(0)
		Display: rigging cost, dollars/hour	1.25
4.	Key in:	Total crew wage, press ENTER↑	(30)
	Key in:	Percent fringe benefits, press ENTER↑	(30)
	Key in:	Travel time (hours/day), press ENTER↑	(0)
	Key in:	Supervision and overhead (percent of direct labor cost), press C	(20)
		Print: operating cost, dollars/hour	57.05
		Display and print: machine rate, dollars/hour	79.13

Section III. Yarding Costs

Unknown production rate:

1. Key in: Average volume per piece as bucked, press ENTER↑ (.1
   Key in: Average number of pieces per turn, press ENTER↑ (3.5
   Key in: Average number of turns per hour, press D (10
   Display: gross production rate, unit volume/hour 3.50

2. Key in: Percent defect in pieces as yarded, press ENTER↑ (10
   Key in: Number of yarding roads in cutting unit, press ENTER↑ (10
   Key in: Time per road change (hours), press ENTER↑ (1
   Key in: Move in and move out cost, press D (2000
   Display: (100-percent defect)/100 0.90

3. Key in: Area of unit, press ENTER↑ (35
   Key in: Yield (unit volume/unit area), press D (40
   Print: remainder of output (see Sample Output, p. 13)

Known production rate:

1. Key in: Production rate (unit volume/hour), press E (3.5
   Display: gross production rate, unit volume/hour 3.50

2. Key in: Percent defect in pieces as yarded, press ENTER↑ (10
   Key in: Number of settings in cutting unit, press ENTER↑ (10
   Key in: Time per setting change (hours), press ENTER↑ (1
   Key in: Move in and move out cost, press E (2000
   Display: (100-percent defect)/100 0.90

3. Key in: Area of unit, press ENTER↑ (35
   Key in: Yield (unit volume/unit area), press E (40
   Print: remainder of output (see Sample Output, p. 13)

Sample Output

During execution, costs and production rates are printed on the HP-97 tape. At completion of the program, the tape output will appear as shown below:

```
22.08  ***   Ownership cost, dollars/hour
57.05  ***   Operating cost, dollars/hour

79.13  ***   Machine rate, dollars/hour

 3.50  ***   Gross production rate, unit volume/hour
 3.15  ***   Net production rate, unit volume/hour

 0.51  ***   Gross road change cost, dollars/unit volume
 1.43  ***   Gross move in and out cost, dollars/unit volume

 0.57  ***   Net road change cost, dollars/unit volume
 1.59  ***   Net move in and out cost, dollars/unit volume

24.54  ***   Gross yarding cost, dollars/unit volume
27.27  ***   Net yarding cost, dollars/unit volume
```

Equipment Ownership Cost

Delivered equipment cost	\$ 140000
Less line and rigging cost	− \$ —
Less tire or track replacement cost	− \$ —
Less residual (salvage) value	− \$ 2800 (= 20%)
Depreciable value	\$ 112000

Equipment depreciation: $\frac{\text{(Depreciable value)}}{\text{(Depreciation period)}} = \frac{(\$\,112000\ )}{(\ 7\ \text{yr})}$ \$ 16000 /yr

Average annual investment: $\frac{\text{(Depreciable value)} \times \text{(Depreciation period + 1)}}{2 \times \text{(Depreciation period)}} + \text{(Residual value)}$

$= \frac{(\$\,112000\ ) \times (\ 8\ )}{2 \times (\ 7\ )} + (\$\,28000\ ) = \$\,92\,000$ /yr

Interest expense: (Annual interest rate) x (Average annual investment) = (12 %) x (\$ 92000 /yr) + \$ 11040 /yr

Taxes, license, insurance & storage: ___% of Average annual investment = (9 %) x (\$ 92000 /yr) + \$ 8280 /yr

Annual ownership cost: \$ 35320 /yr

Annual utilization: (200 days worked/yr) x (8 hours worked/day) = 1600 hr/yr

Ownership cost: $\frac{\text{(Annual ownership cost)}}{\text{(Annual utilization)}} = \frac{(\$\,35320\ /\text{yr})}{(\ 1600\ \text{hr/yr})}$ \$ 22.08 /yr

Equipment Operating Cost

Repairs and maintenance: $\frac{\text{\% of Equipment depreciation}}{\text{Annual utilization}} = \frac{(50\%) \times (\$\ 16000\ /yr)}{(1600\ hr/yr)}$ — \$ 5.00 /hr

Fuel: (2 gal/hr) x (\$ .80 /gal) — + \$ 1.60 /hr

Oil & lubricants: (___% of fuel consumption) x (unit cost) = (5 %) x (____gal/hr) x (\$ 1.50 /gal) — + \$ 0.15 /hr

Lines: $\frac{\text{(Cost)}}{\text{(Estimated life)}} = \frac{(\$\ 3600)}{(1600\ hr)}$ — + \$ 2.25 /hr

Rigging: $\frac{\text{(Cost)}}{\text{(Estimated life)}} = \frac{(\$\ 1000)}{(800\ hr)}$ — + \$ 1.25 /hr

Tires or tracks: $\frac{\text{(Replacement cost)}}{\text{(Estimated life)}} = \frac{(\$\ 0)}{(0\ hr)}$ — + \$ 0 /hr

Crew position: ______ ______ ______ ______ ______ ______

Base wage: \$ 11 /hr + \$ 10 /hr + \$ 9 /hr + \$____/hr + \$____/hr + \$____/hr

Total crew wage: \$ 30 /hr

Direct labor cost: (Total crew wage) x $\left[\frac{\text{(100 + \% fringe benefits)}}{100} + \frac{\text{(travel time/day)}}{\text{(operating time/day)}}\right]$

$= (\$\ 30\ /hr) \times \left[\frac{(100 + 30\%)}{100} + \frac{(0\ hr/day)}{(8\ hr/day)}\right]$ — + \$ 39.00 /hr

Supervision and overhead: ___% of direct labor cost = (20 %) x (\$ 39.00 /hr) — + \$ 7.80 /hr

Operating cost: — \$ 57.05 /hr

Machine rate: (Ownership cost) + (Operating cost) = (\$ 22.08 /hr) + (\$ 57.05 /hr) — \$ 79.13 /hr

Cruise Data

Area of unit: $A =$ 35 acres

Yield per acre : $V =$ 40 cunits/acre

Gross unit volume: $V_T = (V) \times (A) =$ (40 cunits/acre) x (35 acres) = 1400 cunits

Average volume per log as cruised = —

Average volume per piece as bucked: $v =$ .1 cunit

Percent defect in stand as cruised = — %

Percent defect in pieces as yarded: $D =$ 10 %

Engineering Data

Number of settings in cutting unit: $N =$ 10

Average yarding distance = —

Estimates

Average number of pieces per turn: $n =$ 3.5

Average volume per turn: $v_t = (v) \times (n) =$ (.1cunit) x (3.5) = .35 cunits

Average turns per hour: $C =$ 10

Delay as a percentage of turns per hour: $d =$ — %

Adjusted turns per hour: $c = (C) \times \frac{(100 - d)}{100} =$ (10) x $\frac{(100 - \text{—}\ \%)}{100}$ = 10

Time per setting change: $t_s =$ 1 hours

Total setting change time: $T_S = (t_s) \times (N - 1) =$ (1 hr) x (9) = 9 hours

Move-in and move-out cost, M: $ 2000

Calculations

Number of turns: $\frac{\text{(Gross volume, } V_T)}{\text{(Volume per turn, } v_t)} = \frac{(1400\text{ cunits})}{(3.5\text{ cunits})} = \underline{4000}$

Operating time: $\frac{\text{(Number of turns)}}{\text{(Adjusted turns per hour, c)}}$ + Total setting change time

$= \frac{(4000)}{(10)} + \underline{9}\text{ hr} = \underline{409}$ hours

Yarding cost: (Machine rate) x (Operating time) = (\$ 79.13 /hr) x (409 hr) = \$ 32364.17

Add move-in and move-out cost, M: + \$ 2000.00

Total yarding cost: \$ 34364.17

Yarding cost per gross unit volume: $\frac{\text{(Yarding cost)}}{\text{(Gross volume, } V_T)} = \frac{(\$34364.17)}{(1400)} =$ \$ 24.54 / cunit

Net volume: (Gross volume, V_T) x $\frac{(100 - \%\text{ defect, D})}{100} = (1400) \times \frac{(100 - 10\%)}{100} =$ 1260 cunits

Yarding cost per net unit volume: $\frac{\text{(Yarding cost)}}{\text{(Net volume)}} = \frac{(\$34364.17)}{(1260)} =$ \$ 27.27 / cunit

For total logging system cost, add:

Roading cost per net unit volume = + \$_____/_____

Felling cost per net unit volume = + \$_____/_____

Loading cost per net unit volume = + \$_____/_____

Hauling cost per net unit volume = + \$_____/_____

Total logging cost per net unit volume = \$_____/_____

Multiple Equipment

More than one piece of equipment may be analyzed as part of a single yarding operation. For example, a yarder, carriage and rigging hardware can be included in the yarding cost analysis by re-running the program. The steps below should be followed for th second and subsequent pieces of equipment:

1. In Section I, enter the equipment cost, residual and depreciation period.
2. In Section I, re-enter the original values of annual interest rate, taxes, license, insurance, and storage, operating season, and operating time per day.
3. In Section II, enter repairs and maintenance cost, then enter for the remaining variables.
4. In Section III, re-enter the original values for all variable except move-in and move-out costs for which the entry is 0.
5. The tape output values corresponding to ownership cost, operating cost, machine rate, road change cost and yarding cost for each piece of equipment should be added together for the tota cost.

Operation of Desk-Top Computer Program

With the program stored on a tape cartridge, it is executed as follows:

Initial Data Entry

1. Enter GET "YCOST" and execute.
2. Press RUN when program is loaded.

From this point on, visual prompts on the CRT screen will guide further input. A sample keyboard response is shown in parentheses following the underscored prompt message.

The CONT key must be pressed after each entry.

3. <u>Want output on the screen? (YES or NO) - If (NO), output wil be on the printer.</u> (NO)
   Y or N may always be entered in place of YES or NO.

4. <u>Do you want a heading for all output? (YES or NO)</u> (YES)
   If (NO) skip step 5.

5. Enter heading (in any form desired, up to 70 characters maximum).
(SAMPLE OUTPUT)
The characters entered here will be printed as a single line at the top of each section of output; i.e., the output generated by the initial run and keys 1, 2, 3, 11, 12, 13, 14, and 15.

6. Number of pieces of equipment to depreciate = ? (2)
Up to nine pieces of equipment associated with an operation may be entered. One may represent a yarder, another the carriage, etc. If six or more are entered, the following message will be displayed for 7 seconds:

"Screen output may be incomplete for VARIABLE CHANGES & PRINT ANALYSIS routines!"

Some portion of the results may be missing on the screen due to a lack of buffer space for screen output. Resultant cost values will be correct, however, and output on the printer will be complete.

For various entries, such as above, a non-zero value is required. If zero is entered, a message will indicate so and the original prompt will return to allow the value to be re-entered.

7. For piece #1: Equipment identifier (30 characters maximum) = ? (YARDER)

8. For piece #1: Cost of YARDER (dollars) = ? (125000)

9. For piece #1: Residual value (percent of equipment cost) = ? (20)

10. For piece #1: Depreciation period (years) = ? (7)

11. For piece #1: Repairs and maintenance (percent of equipment depreciation, $14286 per year) = ? (50)
The value shown is the amount of equipment depreciation.

12. For piece #2: Equipment identifier (30 characters maximum) = ? (CARRIAGE)

13. For piece #2: Cost of CARRIAGE (dollars) = ? (3000)

14. For piece #2: Residual value (percent of equipment cost) = ? (10)

15. For piece #2: Depreciation period (years) = ? (5)

16. For piece #2: Repairs and maintenance (pct of equip. depr., $540 per year) = ? (20)

17. Annual interest rate (percent) = ? (12)

18. Taxes, license, insurance & storage (pct of avg. ann. invest., $84063) = ? (9)
The value shown is the amount of the average annual investment.

19. Operating season (days worked/year) = ? (200)

20. Operating time per day (hours) = ? (8)

21. Fuel consumption (gallons/hour) = ? (3)

22. Fuel cost (dollars/gallon) = ? (.80)

23. Oil and lube consumption (percent of fuel consumption) = ? (5)

24. Oil and lube cost (dollars/gallon) = ? (1.50)

25. Line cost (dollars) = ? (3600)
If line cost = 0, skip step 26.

26. Estimated line life (hours) = ? (1600)

27. Rigging cost (dollars) = ? (1000)
If rigging cost = 0, skip step 28.

28. Estimated rigging life (hours) = ? (800)

29. Tire or track replacement cost (dollars) = ? (0)
If tire or track replacement cost = 0, skip step 30.

30. Estimated tire or track life (hours) = ?

31. Total crew wage (base wage for all crew members, dollars/hour) = ? (30)

32. Fringe benefits (percent of total crew wage) = ? (30)

33. Travel time per day (hours) = ? (.5)

34. Supervision and overhead (percent of direct labor, \$41 per hour) = ? (20)

Direct labor is expressed algebraically as

$$\text{(total crew wage)} \times \frac{100 + \%\ \text{fringe benefits}}{100} + \frac{\text{travel time/day}}{\text{operating time/day}}$$

35. Volume units = ? (5 characters maximum) (CUNIT)

36. Is known production rate to be entered? (YES or NO) (YES)

Sample output will be shown for both cases. If (NO), continue at step 45.

Known Production Rate - EXAMPLE 1

37. Percent defect in pieces as yarded = ? (0)

38. Number of yarding roads in unit = ? (11)

Total road change time is calculated by multiplying the time per road change by the number of yarding roads in the cutting unit less one. Set-up for the first or only yarding road is mandatory and considered part of move in.

39. Time per road change (hours) = ? (1)

40. Production rate (cunit/hour) = ? (5)

41. Move in and move out cost (dollars) = ? (2000)

42. Cutting unit area (acres) = ? (35)

43. Yield per acre (cunit) = ? (40)

Steps 42 and 43 are required to express the road change cost and move in and move out cost in dollars/unit volume. If total road change time and move in and move out cost are zero, area and yield are not needed.

44. Enter identifier (25 characters maximum) (EXAMPLE 1)

If nothing is entered (i.e., only the CONT key is pressed), no identifier will be used.

Note: Skip remaining steps (45-51).

Calculate Production Rate - EXAMPLE 2

45. Average volume per piece as bucked (cunit) = ? (.14)

46. Percent defect in pieces as yarded = ? (6)

47. Number of yarding roads in unit = ? (1)

No road change time is required for one setting.

48. Average number of pieces per turn = ? (3.5)

49. Average number of turns per hour = ? (12.5)

The value of turns per hour should account for delays.

50. Move in and move out cost (dollars) = ? (0)

51. Enter identifier (25 characters maximum) (EXAMPLE 2)

If nothing is entered (i.e., only the CONT key is pressed) no identifier will be used.

The initial data entry is complete. The results for the two sampl outputs are shown in figures 6 and 7. Yarding cost is the machin rate divided by production rate plus road change cost plus move i and move out cost. When percent defect in pieces yarded equals zero, no distinction is made between gross and net values. In figure 7, however, the difference between gross and net values is due to the percent defect in pieces yarded.

Further action must be initiated through the special function keys. The overlay card, figure 8, defines the keys.

```
SAMPLE OUTPUT


YARDING COST PROGRAM


Values are for EXAMPLE 1


OWNERSHIP COST = $   20.30/HOUR
OPERATING COST = $   59.71 HOUR
                 ---------------
MACHINE RATE =   $   80.01/HOUR

PRODUCTION RATE =     5.00 CUNIT/HOUR

ROAD CHANGE COST = $     .57/CUNIT
MOVE IN AND OUT COST =  $   1.43/CUNIT


YARDING COST = $  18.00/CUNIT
```

Figure 6.--Printed sample output for known production rate.

```
SAMPLE OUTPUT

YARDING COST PROGRAM

Values are for EXAMPLE 2

OWNERSHIP COST = $   20.30/HOUR
OPERATING COST = $   59.71/HOUR
                 ---------------
MACHINE RATE =   $   80.01/HOUR

GROSS PRODUCTION RATE =    6.13 CUNIT/HOUR

NET PRODUCTION RATE =      5.76 CUNIT/HOUR


GROSS YARDING COST = $  13.06/CUNIT

NET YARDING COST =   $  13.90/CUNIT
```

Figure 7.--Printed sample output for calculated production rate.

SPECIAL FUNCTIONS

S					Base values replaced by new values			
	Variable changes	Print analysis	Part 1	Part 2	New values replaced by base values	Output on screen	Output on printer	Rewind T15
S	Hard copy of plot		Plot only					
	Plot on screen	Plot on plotter	Axes and plot	Change ownership cost	Change operating cost	Change machine rate	Change gross volume/hour	Change net volume/hour

igure 8.--Special function key overlay.

Key 5 - Output on Screen

All future output will be displayed on the CRT screen.

Key 6 - Output on Printer

All future output will be printed on the internal printer.

Key 1 - Print Analysis

The values of all variables will be displayed along with the resultant costs and production rates. Each variable is numbered, and the "base values" correspond to the initial data entered previously. The "new values" and "percent change" are explained under Key 0 - Variable Changes. Until a variable is changed with Key 0, the "new values" equal the "base values" and "percent change" is zero. Figures 9 and 10 present the base values entered previously as EXAMPLE 1 and EXAMPLE 2.

For output on the screen, the variables up to number 22 will be displayed. Key 3 must be pressed to display the remainder of the analysis.

Key 2 - Part 1

For output on the screen, this key displays the variables up to number 22 exactly as Key 1 does in the output-on-screen mode.

Key 3 - Part 2

For output on the screen, the remainder of the variables and/or the resultant costs and production rates are displayed.

AMPLE OUTPUT

NALYSIS OF VARIABLE CHANGES　　　　BASE VALUES = EXAMPLE 1
　　　　　　　　　　　　　　　　　NEW VALUES = EXAMPLE 1

	BASE VALUES	NEW VALUES	PERCENT CHANGE
#1 COST OF yarder (DOLLARS)	125000	125000	0.0
#2 COST OF carriage (DOLLARS)	3000	3000	0.0
#1 RESIDUAL (PERCENT OF EQUIPMENT COST)	20	20	0.0
#2 RESIDUAL (PERCENT OF EQUIPMENT COST)	10	10	0.0
#1 DEPRECIATION PERIOD (YEARS)	7	7	0.0
#2 DEPRECIATION PERIOD (YEARS)	5	5	0.0
#1 REPAIRS & MAINTENANCE (PERCENT OF DEPRECIATION)	50	50	0.0
#2 REPAIRS & MAINTENANCE (PERCENT OF DEPRECIATION)	20	20	0.0
ANNUAL INTEREST RATE (PERCENT)	12.00	12.00	0.0
TAX,LICENSE,INSURANCE, AND STORAGE (PERCENT)	9.00	9.00	0.0
OPERATING SEASON (DAYS WORKED/YEAR)	200	200	0.0
OPERATING TIME PER DAY (HOURS)	8.0	8.0	0.0
FUEL CONSUMPTION (GALLONS/HOUR)	3.00	3.00	0.0
0 FUEL COST (DOLLARS/GALLON)	.80	.80	0.0
1 OIL AND LUBE (PERCENT OF FUEL CONSUMPTION)	5	5	0.0
2 OIL AND LUBE COST (DOLLARS/GALLON)	1.50	1.50	0.0
3 LINE COST (DOLLARS)	3600	3600	0.0
4 LINE LIFE (HOURS)	1600	1600	0.0
5 RIGGING COST (DOLLARS)	1000	1000	0.0
6 RIGGING LIFE (HOURS)	800	800	0.0
7 TIRE OR TRACK REPLACEMENT COST (DOLLARS)	0	0	0.0
8 TIRE OR TRACK LIFE (HOURS)	0	0	0.0
9 TOTAL CREW WAGE (DOLLARS/HOUR)	30.00	30.00	0.0
0 FRINGE BENEFITS (PERCENT OF TOTAL CREW WAGE)	30	30	0.0
1 TRAVEL TIME PER DAY (HOURS)	.50	.50	0.0
2 SUPERVISION AND OVERHEAD (PERCENT OF DIRECT LABOR)	20	20	0.0
3 CUTTING UNIT AREA (ACRES)	35	35	0.0
4 YIELD PER ACRE (CUNIT)	40.00	40.00	0.0
5 DEFECT IN PIECES AS YARDED (PERCENT)	0.00	0.00	0.0
7 NUMBER OF YARDING ROADS IN UNIT	11	11	0.0
9 TIME PER ROAD CHANGE (HOURS)	1.00	1.00	0.0
1 MOVE IN AND MOVE OUT COST (DOLLARS)	2000	2000	0.0
WNERSHIP COST (DOLLARS/HOUR)	20.30	20.30	0.0
PERATING COST (DOLLARS/HOUR)	59.71	59.71	0.0
	------	------	
ACHINE RATE (DOLLARS/HOUR)	80.01	80.01	0.0
RODUCTION RATE (CUNIT/HOUR)	5.00	5.00	0.0
OAD CHANGE COST (DOLLARS/CUNIT)	.57	.57	0.0
OVE IN AND OUT COST (DOLLARS/CUNIT)	1.43	1.43	0.0
ARDING COST (DOLLARS/CUNIT)	18.00	18.00	0.0

Figure 9.--Printed output from key 1 (Print analysis) for EXAMPLE 1.

SAMPLE OUTPUT

ANALYSIS OF VARIABLE CHANGES — BASE VALUES = EXAMPLE 2; NEW VALUES = EXAMPLE 2

		BASE VALUES	NEW VALUES	PERCENT CHANGE
1	#1 COST OF yarder (DOLLARS)	125000	125000	0.
	#2 COST OF carriage (DOLLARS)	3000	3000	0.
2	#1 RESIDUAL (PERCENT OF EQUIPMENT COST)	20	20	0.
	#2 RESIDUAL (PERCENT OF EQUIPMENT COST)	10	10	0.
3	#1 DEPRECIATION PERIOD (YEARS)	7	7	0.
	#2 DEPRECIATION PERIOD (YEARS)	5	5	0.
4	#1 REPAIRS & MAINTENANCE (PERCENT OF DEPRECIATION)	50	50	0.
	#2 REPAIRS & MAINTENANCE (PERCENT OF DEPRECIATION)	20	20	0.
5	ANNUAL INTEREST RATE (PERCENT)	12.00	12.00	0.
6	TAX,LICENSE,INSURANCE, AND STORAGE (PERCENT)	9.00	9.00	0.
7	OPERATING SEASON (DAYS WORKED/YEAR)	200	200	0.
8	OPERATING TIME PER DAY (HOURS)	8.0	8.0	0.
9	FUEL CONSUMPTION (GALLONS/HOUR)	3.00	3.00	0.
10	FUEL COST (DOLLARS/GALLON)	.80	.80	0.
11	OIL AND LUBE (PERCENT OF FUEL CONSUMPTION)	5	5	0.
12	OIL AND LUBE COST (DOLLARS/GALLON)	1.50	1.50	0.
13	LINE COST (DOLLARS)	3600	3600	0.
14	LINE LIFE (HOURS)	1600	1600	0.
15	RIGGING COST (DOLLARS)	1000	1000	0.
16	RIGGING LIFE (HOURS)	800	800	0.
17	TIRE OR TRACK REPLACEMENT COST (DOLLARS)	0	0	0.
18	TIRE OR TRACK LIFE (HOURS)	0	0	0.
19	TOTAL CREW WAGE (DOLLARS/HOUR)	30.00	30.00	0.
20	FRINGE BENEFITS (PERCENT OF TOTAL CREW WAGE)	30	30	0.
21	TRAVEL TIME PER DAY (HOURS)	.50	.50	0.
22	SUPERVISION AND OVERHEAD (PERCENT OF DIRECT LABOR)	20	20	0.
25	AVG. VOLUME/PIECE AS BUCKED (CUNIT)	.14	.14	0.
26	DEFECT IN PIECES AS YARDED (PERCENT)	6.00	6.00	0.
27	NUMBER OF YARDING ROADS IN UNIT	1	1	0.
28	AVERAGE NUMBER OF PIECES PER TURN	3.50	3.50	0.
29	AVERAGE NUMBER OF TURNS PER HOUR	12.50	12.50	0.
30	TIME PER ROAD CHANGE (HOURS)	0.00	0.00	0.
31	MOVE IN AND MOVE OUT COST (DOLLARS)	0	0	0.
	OWNERSHIP COST (DOLLARS/HOUR)	20.30	20.30	0.
	OPERATING COST (DOLLARS/HOUR)	59.71	59.71	0.
		------	------	
	MACHINE RATE (DOLLARS/HOUR)	80.01	80.01	0.
	GROSS PRODUCTION RATE (CUNIT/HOUR)	6.13	6.13	0.
	NET PRODUCTION RATE (CUNIT/HOUR)	5.76	5.76	0.
	GROSS YARDING COST (DOLLARS/CUNIT)	13.06	13.06	0.
	NET YARDING COST (DOLLARS/CUNIT)	13.90	13.90	0.

Figure 10.--Printed output from key 1 (Print analysis) for EXAMPLE 2.

Key 0 - Variable Changes

This routine allows changes to be made in the initial or "base values" and computes the resulting costs. The procedure, with sample input corresponding to EXAMPLE 2, is as follows:

1. The number of the variable to be changed = ? (1)
   This is the number that corresponds to each variable as shown in figure 8 or 9. In this case, equipment cost.

2. For what piece (#) of equipment? (1)
   The yarder cost will be changed.

3. Do you want to delete this piece of equipment (YES or NO) (NO)

4. BASE VALUE = 125000 LAST VALUE = 125000 NEW VALUE = ? (200000)
   LAST VALUE refers to the previous new value entered. It equals the base value unless a new value has been entered.

5. Any more variable changes desired? (YES or NO) (YES)

6. The number of the variable to be changed = ? (21)

   It is desired to change travel time per day (variable number 21).

7. BASE VALUE = .50 LAST VALUE = .50 NEW VALUE = ? (0)

8. Any more variable changes desired (YES or NO) (YES)

9. The number of the variable to be changed = ? (1)
   It is desired to change equipment cost.

10. For what piece (#) of equipment? (2)
    The carriage cost will be changed.

11. Do you want to delete this piece of equipment? (YES or NO) (YES)

12. Any more variable changes desired (YES or NO) (YES)

13. The number of the variable to be changed = ? (1)

14. For what piece (#) of equipment? (4)
    It is desired to add a piece of equipment to the existing pieces in the base values. Since there are only two, and pieces are only added in sequence, the following message will be displayed:
    "Note: the piece # you selected is changed to 3. Press CONT to proceed."

15. Equipment identifier (30 characters maximum) for piece #3 = ?
(RIGGING HARDWARE)

16. For piece #3: Cost of RIGGING HARDWARE (dollars) = ?
(5000)

17. For piece #3: Residual value (percent of equipment cost) = ?
(10)

18. For piece #3: Depreciation period (years) = ? (0)
A depreciation period of zero years is not allowed, and the following message is displayed for 6 seconds:
"The value of 0 may not be entered for this variable! It must be re-entered."

19. For piece #3: Depreciation period (years) = ? (4)

20. For piece #3: Repairs and maintenance (percent of equipment depreciation = ? (0)

21. Any more variable changes desired? (YES or NO) (NO)

22. Enter identifier for NEW VALUES (25 characters maximum)
(EXAMPLE 2 UPDATE)
If nothing is entered (i.e., only the CONT key is pressed) the identifier for the new values will be the same as that for the base values. However, once an identifier is entered, when step 22 is encountered in a subsequent VARIABLE CHANGES routine and nothing is entered, the identifier for the new values will remain unchanged.

23. Enter a new heading for all output (70 characters maximum)
If nothing is entered (i.e., only the CONT key is pressed) the existing heading will remain unchanged.

The variable changes are complete. Output can be obtained by pressing key 1, key 2, or key 3. For output on the printer, pressing key 1 yields the results shown in figure 11.

SAMPLE OUTPUT

ANALYSIS OF VARIABLE CHANGES — BASE VALUES = EXAMPLE 2; NEW VALUES = EXAMPLE 2 UPDATE

			BASE VALUES	NEW VALUES	PERCENT CHANGE
1	#1 COST OF yarder	(DOLLARS)	125000	200000	60.0
	#2 COST OF carriage	(DOLLARS)	3000	0	-100.0
	#3 COST OF rigging hardware	(DOLLARS)	0	5000	100.0
2	#1 RESIDUAL (PERCENT OF EQUIPMENT COST)		20	20	0.0
	#2 RESIDUAL (PERCENT OF EQUIPMENT COST)		10	0	-100.0
	#3 RESIDUAL (PERCENT OF EQUIPMENT COST)		0	10	100.0
3	#1 DEPRECIATION PERIOD (YEARS)		7	7	0.0
	#2 DEPRECIATION PERIOD (YEARS)		5	0	-100.0
	#3 DEPRECIATION PERIOD (YEARS)		0	4	100.0
4	#1 REPAIRS & MAINTENANCE (PERCENT OF DEPRECIATION)		50	50	0.0
	#2 REPAIRS & MAINTENANCE (PERCENT OF DEPRECIATION)		20	0	-100.0
	#3 REPAIRS & MAINTENANCE (PERCENT OF DEPRECIATION)		0	0	0.0
5	ANNUAL INTEREST RATE (PERCENT)		12.00	12.00	0.0
6	TAX,LICENSE,INSURANCE, AND STORAGE (PERCENT)		9.00	9.00	0.0
7	OPERATING SEASON (DAYS WORKED/YEAR)		200	200	0.0
8	OPERATING TIME PER DAY (HOURS)		8.0	8.0	0.0
9	FUEL CONSUMPTION (GALLONS/HOUR)		3.00	3.00	0.0
10	FUEL COST (DOLLARS/GALLON)		.80	.80	0.0
11	OIL AND LUBE (PERCENT OF FUEL CONSUMPTION)		5	5	0.0
12	OIL AND LUBE COST (DOLLARS/GALLON)		1.50	1.50	0.0
13	LINE COST (DOLLARS)		3600	3600	0.0
14	LINE LIFE (HOURS)		1600	1600	0.0
15	RIGGING COST (DOLLARS)		1000	1000	0.0
16	RIGGING LIFE (HOURS)		800	800	0.0
17	TIRE OR TRACK REPLACEMENT COST (DOLLARS)		0	0	0.0
18	TIRE OR TRACK LIFE (HOURS)		0	0	0.0
19	TOTAL CREW WAGE (DOLLARS/HOUR)		30.00	30.00	0.0
20	FRINGE BENEFITS (PERCENT OF TOTAL CREW WAGE)		30	30	0.0
21	TRAVEL TIME PER DAY (HOURS)		.50	0.00	-100.0
22	SUPERVISION AND OVERHEAD (PERCENT OF DIRECT LABOR)		20	20	0.0
25	AVG. VOLUME/PIECE AS BUCKED (CUNIT)		.14	.14	0.0
26	DEFECT IN PIECES AS YARDED (PERCENT)		6.00	6.00	0.0
27	NUMBER OF YARDING ROADS IN UNIT		1	1	0.0
28	AVERAGE NUMBER OF PIECES PER TURN		3.50	3.50	0.0
29	AVERAGE NUMBER OF TURNS PER HOUR		12.50	12.50	0.0
30	TIME PER ROAD CHANGE (HOURS)		0.00	0.00	0.0
31	MOVE IN AND MOVE OUT COST (DOLLARS)		0	0	0.0

	BASE VALUES	NEW VALUES	PERCENT CHANGE
OWNERSHIP COST (DOLLARS/HOUR)	20.30	32.67	61.0
OPERATING COST (DOLLARS/HOUR)	59.71	60.07	.6
	------	------	
MACHINE RATE (DOLLARS/HOUR)	80.01	92.74	15.9
GROSS PRODUCTION RATE (CUNIT/HOUR)	6.13	6.13	0.0
NET PRODUCTION RATE (CUNIT/HOUR)	5.76	5.76	0.0
GROSS YARDING COST (DOLLARS/CUNIT)	13.06	15.14	15.9
NET YARDING COST (DOLLARS/CUNIT)	13.90	16.11	15.9

Figure 11.--Printed output from key 1 (Print analysis) for EXAMPLE 2.

Keys 11, 12, 13, 14 and 15

The values of ownership cost, operating cost, machine rate, gross volume/hour (i.e., gross production rate), and net volume/hour (i.e., net production rate) can be changed with these keys. As an example, the output in figure 11 is modified by pressing key 14 and changing gross volume/hour as follows:

1. GROSS VOLUME/HR: BASE VALUE = 6.13 LAST VALUE = 6.13
   NEW VALUE = ? (8)

2. Enter identifier for NEW VALUES (25 characters maximum)
   If nothing is entered (i.e., only the CONT key is pressed), the existing identifier for the new values will remain unchanged.

3. Enter a new heading for all output (25 characters maximum)
   If nothing is entered (i.e., only the CONT key is pressed), the existing heading will remain unchanged.

For output on the printer, the results shown in figure 12 are generated.

```
SAMPLE OUTPUT

ANALYSIS WITH NEW VALUE OF          BASE VALUES = EXAMPLE 2
GROSS VOLUME/HR                     NEW VALUES =  EXAMPLE 2 UPDATE

                                               BASE      NEW     PERCENT
                                              VALUES    VALUES    CHANGE

OWNERSHIP COST (DOLLARS/HOUR)                  20.30     32.67     61.0
OPERATING COST (DOLLARS/HOUR)                  59.71     60.07       .6
                                              ------    ------
MACHINE RATE (DOLLARS/HOUR)                    80.01     92.74     15.9

GROSS PRODUCTION RATE (CUNIT/HOUR)              6.13      8.00     30.6

NET PRODUCTION RATE (CUNIT/HOUR)                5.76      5.76      0.0


GROSS YARDING COST (DOLLARS/CUNIT)             13.06     11.59    -11.3

NET YARDING COST (DOLLARS/CUNIT)               13.90     16.11     15.9
```

Figure 12.--Printed output from key 14 (Change gross volume/hour) for EXAMPLE 2.

Key 8 - Plot on Screen

When a peripheral plotter is not available or it is desired to first view the yarding cost-production rate curve on the screen, this key must be pressed. Key 10 or key 26 must be pressed to make the actual plot.

Key 9 - Plot on Plotter

The yarding cost-production rate curve will be plotted directly on the plotter. Physical plotting limits should be set to 6-1/4 inches horizontally and vertically. Key 10 or key 26 must be pressed to make the actual plot.

If this key is pressed, the plotter must be turned on before proceeding.

Key 10 - Axes and Plot

This key is used to construct the axes, label them, and plot the yarding cost-production rate curves. Key 8 or key 9 must be pressed before this key. The procedures, with sample inputs corresponding to EXAMPLE 2 UPDATE (figure 12) follow. It is assumed that key 8 has been pressed.

1. Do you want to plot gross rather than net values? (YES or NO) (YES)

   Step 1 is skipped if gross and net values are equal; i.e., if percent defects is zero.

2. Want to define range of production rate and yarding cost other than 10 and 20 (YES/NO)? (YES)

   The values displayed represent the limits of the X and Y axes respectively, rounded up to the nearest whole value of 10.

   If (NO) is answered, skip step 3.

3. Enter: maximum production rate (X axis), maximum yarding cost (Y axis) (10, 30)

   Any values may be entered but the limits will be rounded up to the nearest whole value of 10. This input is useful for changing the scale of the plot, or when subsequent curves will be added to the current plot (key 26 - Plot only).

4. Enter: 0 to plot BASE VALUES; 1 to plot NEW VALUES; 2 to plot both (2)

   Either or both curves can be plotted on the axes.

Key 26 - Plot Only

Up to nine curves can be plotted on the same axes. The original curve(s) plotted with key 10 (Axes and Plot) and any other curves plotted with key 26 (Plot only) are replotted along with the current base and/or new values on the axes originally defined in step 4, key 10. Each curve is plotted using a different line type. Input is made in response to the following prompt message:

Enter: 0 to plot BASE VALUES; 1 to plot NEW VALUES; 2 to plot both

A new curve can be generated only if one or more changes are made through key 0, 11, 12, 13, 14, or 15 prior to pressing this key.

Key 24 - Hard Copy of Plot

A hard copy on the internal printer is made if the yarding cost-production rate curve was plotted on the screen. The curves representing the new and base values from EXAMPLE 2 UPDATE (fig. 12) are reproduced on the internal printer as shown in figure 13.

Key 4 - New Values Replaced by Base Values

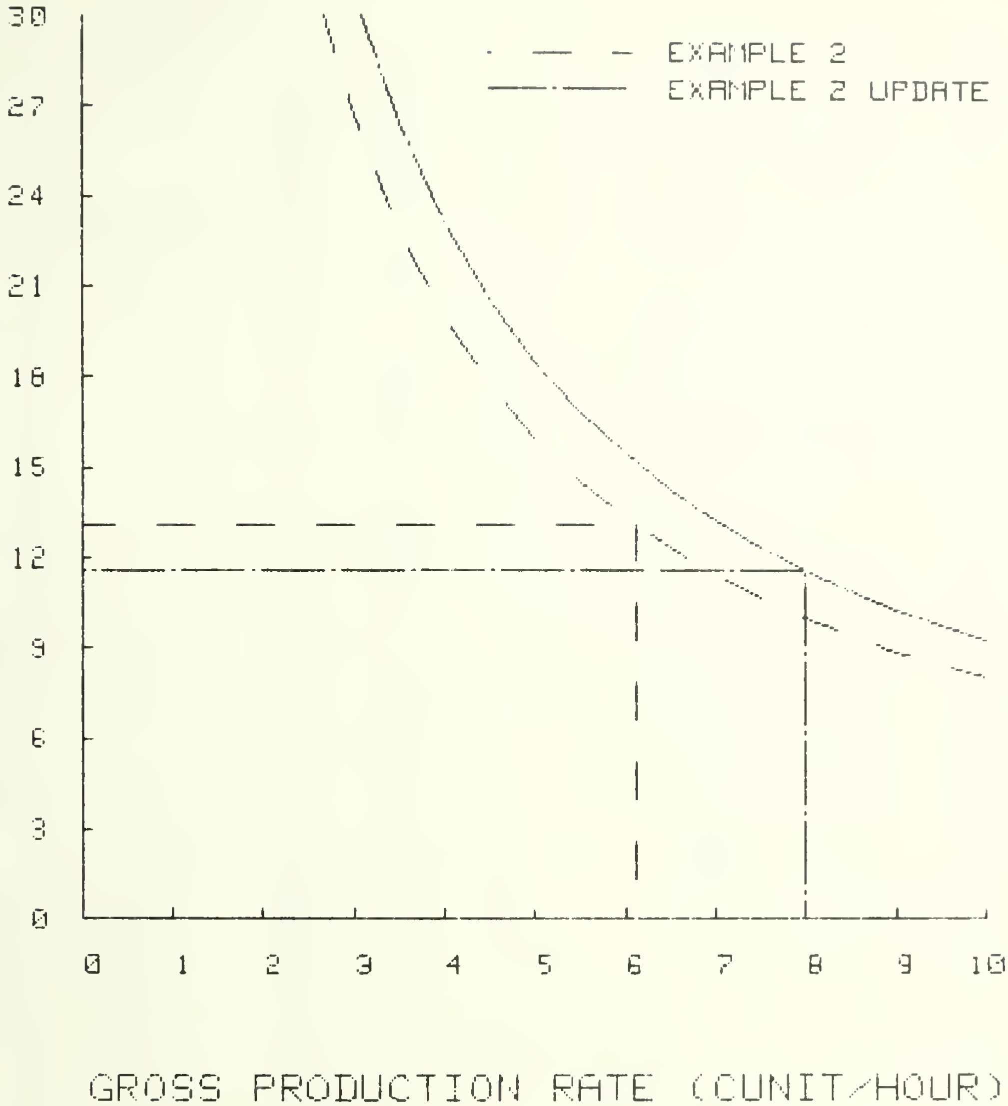
The new values are replaced by the base values, including identifier and resultant costs and production rates. The cost and production rate changes made with keys 11, 12, 13, 14, and 15 act on the new value, not the base value. Thus, if it is desired to see the effect on yarding cost of changing only ownership cost and subsequently to see the effect of changing only operating cost, key 4 must be pressed after key 11 and before key 12.

Key 20 - Base Values Replaced by New Values

The base values are replaced by the new values, including identifier and resultant costs and production rates.

Key 7 - Rewind T15

Rewind the T15 tape cartridge.



iure 13.--Printed output from key 24 (Hard copy of plot) for XMPLE 2.

Program Listings

P 97/67 Program

```
001  *LBLA    21 11
002  STOD     35 14
003  R↓         -31
004  ENT↑       -21
005  R↓         -31
006  R↓         -31
007  ENT↑       -21
008  R↑       16-31
009  %           55
010  STO8     35 08
011  -          -45
012  STOB     35 12
013  RCLD     36 14
014  ÷          -24
015  STOC     35 13
016  RTN         24
017  *LBLA    21 11
018  STO4     35 04
019  X⇄Y        -41
020  ×          -35
021  STO9     35 09
022  R↓         -31
023  RCLD     36 14
024  1           01
025  +          -55
026  RCLB     36 12
027  ×          -35
028  2           02
029  ÷          -24
030  RCLD     36 14
031  ÷          -24
032  RCL8     36 08
033  +          -55
034  STOA     35 11
035  X⇄Y        -41
036  1           01
037  %           55
038  X⇄Y        -41
039  R↓         -31
040  ×          -35
041  STO0     35 00
042  R↓         -31
043  1           01
044  %           55
045  RCLA     36 11
046  ×          -35
047  RCLC     36 13
048  RCL0     36 00
049  +          -55
050  +          -55
051  RCL9     36 09
052  ÷          -24
053  STO5     35 05
054  PRTX       -14
055  RTN         24
056  *LBLC    21 13
057  X⇄Y        -41
058  STO2     35 02
059  ×          -35
060  STO0     35 00
061  R↓         -31
062  RCLC     36 13
063  %           55
064  RCL5     36 05
065  ÷          -24
066  ST+0  35-55 00
067  RTN         24
068  *LBLC    21 13
069  X=0?     16-43
070  GTO1     22 01
071  ÷          -24
072  ST+0  35-55 00
073  *LBL2    21 02
074  R↓         -31
075  %           55
076  RCL2     36 02
077  ×          -35
078  ST+0  35-55 00
079  RTN         24
080  *LBLC    21 13
081  X=0?     16-43
082  GTO3     22 03
083  ÷          -24
084  ST+0  35-55 00
085  *LBL4    21 04
086  R↓         -31
087  X=0?     16-43
088  GTO5     22 05
089  ÷          -24
090  *LBL5    21 05
091  ST+0  35-55 00
092  RTN         24
093  *LBLC    21 13
094  STO1     35 01
095  R↓         -31
096  RCL4     36 04
097  ÷          -24
098  X⇄Y        -41
099  1           01
100  %           55
101  X⇄Y        -41
102  R↓         -31
103  1           01
104  +          -55
105  +          -55
106  ×          -35
107  RCL1     36 01
108  %           55
109  +          -55
110  ST+0  35-55 00
111  RCL0     36 00
112  PRTX       -14
113  SPC      16-11
114  RCL5     36 05
115  +          -55
116  STO6     35 06
117  PRTX       -14
118  SPC      16-11
119  SPC      16-11
120  RTN         24
121  *LBL1    21 01
122  ST+0  35-55 00
123  R↓         -31
124  GTO2     22 02
125  *LBL3    21 03
126  ST+0  35-55 00
127  R↓         -31
128  GTO4     22 04
129  *LBLD    21 14
130  ×          -35
131  ×          -35
132  STOD     35 14
133  RTN         24
134  *LBLD    21 14
135  GTO6     22 06
136  *LBLE    21 15
137  STOD     35 14
138  RTN         24
139  *LBLE    21 15
140  *LBL6    21 06
141  STOA     35 11
142  R↓         -31
143  X⇄Y        -41
144  1           01
145  -          -45
146  ×          -35
147  RCL6     36 06
148  ×          -35
149  STOB     35 12
150  R↑       16-31
151  1           01
152  %           55
153  1           01
154  X⇄Y        -41
155  -          -45
156  STOC     35 13
157  RTN         24
158  *LBLE    21 15
159  *LBL9    21 09
160  ×          -35
161  X=0?     16-43
162  GTO7     22 07
163  ENT↑       -21
164  RCLA     36 11
165  X⇄Y        -41
166  ENT↑       -21
167  R↓         -31
168  ÷          -24
169  STOA     35 11
170  R↓         -31
171  R↓         -31
172  RCLB     36 12
173  X⇄Y        -41
174  ÷          -24
175  STOB     35 12
176  GTO8     22 08
177  *LBL7    21 07
178  0           00
179  STOA     35 11
180  STOB     35 12
181  *LBL8    21 08
182  RCL6     36 06
183  RCLD     36 14
184  PRTX       -14
185  ÷          -24
186  STO1     35 01
187  RCLD     36 14
188  RCLC     36 13
189  ×          -35
190  PRTX       -14
191  SPC      16-11
192  RCL6     36 06
193  X⇄Y        -41
194  ÷          -24
195  STO2     35 02
196  RCLB     36 12
197  PRTX       -14
198  ST+1  35-55 01
199  RCLA     36 11
200  PRTX       -14
201  SPC      16-11
202  ST+1  35-55 01
203  RCLC     36 13
204  R↓         -31
205  X⇄Y        -41
206  RCLC     36 13
207  ÷          -24
208  PRTX       -14
209  ST+2  35-55 02
210  R↓         -31
211  RCLC     36 13
212  ÷          -24
213  PRTX       -14
214  ST+2  35-55 02
215  SPC      16-11
216  SPC      16-11
217  RCL1     36 01
218  PRTX       -14
219  RCL2     36 02
220  PRTX       -14
221  SPC      16-11
222  RTN         24
223  *LBLD    21 14
224  GTO9     22 09
```

9845 Program

```
10   ! ***** YCOST ***** RON MIFFLIN ***** PNW-SEATTLE,USFS ***** NOV,1979 ****
20   !
30   LOAD KEY "K-COST"
40   INPUT "Want output on the screen? (YES or NO)  -  If NO, output will be on
the printer.",B$
50   IF B$[1,1]="Y" THEN 90
60   IF B$[1,1]<>"N" THEN 40
70   P1=0
80   GOTO 100
90   P1=16
100  B$=""
110  PRINTER IS P1
120  A(32)=B(32)=1
130  DATA 1,3,5,7,8,9,10,11,12,19,23,24,25,27,26,29
140  GCLEAR
150  SHORT A(39),B(39),C(9,7),D(9,7),E(40),Z7(2),Z8(2)
160  SHORT A,A1,A2,A3,A4,A5,A6,A7,A8,A9,B,D,E,F,H,H1,I,J,K,K1,K2,K3,L,M,M1,N,N1,1
P,P1,Q,R,S2,T,U,W,W1,X,X1,Z5
170  DIM A$[100],B$[100],C$[100],D$[100],E$[15],F$[100],G$(5)[100],H$[100]
180  DEFAULT ON
190  INPUT "Do you want a heading for all output? (YES or NO)",B$
200  IF B$[1,1]="Y" THEN 240
210  IF B$[1,1]<>"N" THEN 190
220  H$=B$=""
230  GOTO 330
240  INPUT "Enter heading (in any form desired up to 70 characters maximum).",H$
250  IF LEN(H$)<=70 THEN 310
260  BEEP
270  FIXED 0
280  DISP "Sorry, you're";LEN(H$)-70;"characters over the limit of 70!  Try agai
n: heading = ";
290  INPUT H$
300  GOTO 250
310  B$=""
320  PRINT H$,LIN(2)
330  PRINT "YARDING COST PROGRAM",LIN(2)
340  INPUT "Number of pieces of equipment to depreciate = ?",U
350  M=U
360  IF U<=9 THEN 400
370  BEEP
380  INPUT "9 pieces maximum! Try again: number of pieces of equipment to deprec
iate = ?",U
390  GOTO 350
400  IF U<>0 THEN 440
410  BEEP
420  INPUT "Min. of 1 required! Try again: number of pieces of equipment to depr
eciate = ?",U
430  GOTO 350
440  IF U<6 THEN 480
450  BEEP
460  DISP "Screen output may be incomplete for VARIABLE CHANGES & PRINT ANALYSIS
 routines!"
```

```
WAIT 7000
FIXED 0
IF U>1 THEN 680
INPUT "Enter equipment identifier (30 characters maximum).",G$(1)
IF LEN(G$(1))<=30 THEN 550
BEEP
INPUT "30 characters maximum!  Try again: enter equipment identifer.",G$(1)
GOTO 510
DISP "Cost of ";G$(1);" (dollars) = ";
INPUT C(1,1)
IF C(1,1)<>0 THEN 600
GOSUB 2230
GOTO 500
INPUT "Residual (percent of equipment cost) = ?",C(1,2)
INPUT "Depreciation period (years) = ?",C(1,3)
IF C(1,3)<>0 THEN 650
GOSUB 2230
GOTO 610
DISP "Repairs and maintenance (percent of equipment depreciation,$";C(1,1)*
00-C(1,2))/100/C(1,3);"per year) =";
INPUT C(1,4)
GOTO 910
FOR X=1 TO U
DISP "For piece #";X;":  Equipment identifier (30 characters maximum) = ";
INPUT G$(X)
IF LEN(G$(X))<=30 THEN 760
BEEP
DISP "30 characters maximum!  Try again: for piece #";X;": equipment identi
er = ";
INPUT G$(X)
GOTO 710
DISP "For piece #";X;":  Cost of ";G$(X);" (dollars) = ";
INPUT C(X,1)
IF C(X,1)<>0 THEN 810
GOSUB 2230
GOTO 760
DISP "For piece #";X;":  Residual value (percent of equipment cost) = ";
INPUT C(X,2)
DISP "For piece #";X;":  Depreciation period (years) = ";
INPUT C(X,3)
IF C(X,3)<>0 THEN 880
GOSUB 2230
GOTO 830
DISP "For piece #";X;":  Repairs & maintenance (pct of equip. depr., $";C(X
1)*(100-C(X,2))/100/C(X,3);"per yr)=";
INPUT C(X,4)
NEXT X
INPUT "Annual interest rate (percent) = ?",A(5)
MAT D=C
A=D=M1=0
FOR X=1 TO U
D(X,5)=D(X,1)*(100-D(X,2))/100      ! depreciable value
IF D(X,3)<>0 THEN 990
```

```
970  D(X,6)=0
980  GOTO 1000
990  D(X,6)=D(X,5)/D(X,3)        ! equipment depreciation
1000 D=D+D(X,6)       ! total equipment depreciation
1010 IF D(X,3)<>0 THEN 1040
1020 D(X,7)=D(X,1)*D(X,2)/100       ! average annual investment
1030 GOTO 1050
1040 D(X,7)=D(X,5)*(D(X,3)+1)/(2*D(X,3))+D(X,1)*D(X,2)/100  ! avg annual invest.
1050 A=A+D(X,7)       ! total average annual investment
1060 IF P=0 THEN 1080
1070 M1=M1+D(X,4)*D(X,6)/(B(7)*B(8)/100)       ! total repairs & maintenance cost
1080 NEXT X
1090 IF P=1 THEN 2470       ! go to routine to calculate production rate & costs
1100 DISP "Taxes,license,insurance, & storage (pct of avg. ann. invest., $";A;"p
er yr)=";
1110 INPUT A(6)
1120 INPUT "Operating season (days worked/year) = ?",A(7)
1130 IF A(7)<>0 THEN 1160
1140 GOSUB 2230
1150 GOTO 1120
1160 INPUT "Operating time per day (hours) = ?",A(8)
1170 IF A(8)<>0 THEN 1200
1180 GOSUB 2230
1190 GOTO 1160
1200 INPUT "Fuel consumption (gallons/hour) = ?",A(9)
1210 IF A(9)<>0 THEN 1240
1220 GOSUB 2230
1230 GOTO 1200
1240 INPUT "Fuel cost (dollars/gallon) = ?",A(10)
1250 IF A(10)<>0 THEN 1280
1260 GOSUB 2230
1270 GOTO 1240
1280 INPUT "Oil and lube consumption (percent of fuel consumption) = ?",A(11)
1290 IF A(11)<>0 THEN 1320
1300 GOSUB 2230
1310 GOTO 1280
1320 INPUT "Oil and lube cost (dollars/gallon) = ?",A(12)
1330 IF A(12)<>0 THEN 1360
1340 GOSUB 2230
1350 GOTO 1320
1360 INPUT "Line cost (dollars) = ?",A(13)
1370 IF A(13)=0 THEN 1390
1380 INPUT "Estimated line life (hours) = ?",A(14)
1390 INPUT "Rigging cost (dollars) = ?",A(15)
1400 IF A(15)=0 THEN 1420
1410 INPUT "Estimated rigging life (hours) = ?",A(16)
1420 INPUT "Tire or track replacement cost (dollars) = ?",A(17)
1430 IF A(17)=0 THEN 1450
1440 INPUT "Estimated tire or track life (hours) = ?",A(18)
1450 INPUT "Total crew wage (base wage for all crew members, dollars/hour) = ?",
A(19)
1460 IF A(19)<>0 THEN 1490
1470 GOSUB 2230
```

```
GOTO 1450
INPUT "Fringe benefits (percent of total crew wage) = ?",A(20)
INPUT "Travel time per day (hours) = ?",A(21)
DISP "Supervision and overhead (percent of direct labor, $";A(19)*(1+A(20)
+A(21)/A(8));"per hour) = ";
INPUT A(22)
INPUT "Volume units = ? (5 characters maximum)",A$
IF LEN(A$)<=5 THEN 1580
BEEP
INPUT "5 characters maximum! Try again: volume units = ?",A$
GOTO 1540
INPUT "Is known production rate to be entered? (YES or NO)",B$
IF B$[1,1]="N" THEN 1930
IF B$[1,1]<>"Y" THEN 1580
INPUT "Percent defect in pieces as yarded = ?",A(26)
INPUT "Number of yarding roads in unit = ?",A(27)
IF A(27)>1 THEN 1670
IF A(27)<>0 THEN 1680
GOSUB 2230
GOTO 1620
INPUT "Time per road change (hours) = ?",A(30)
B$=""
DISP "Production rate (";LWC$(A$);"/hour) = ";
INPUT A(36)       ! gross production rate
IF A(36)<>0 THEN 1740
GOSUB 2230
GOTO 1680
B(36)=A(36)
A(37)=B(37)=A(36)*(100-A(26))/100       ! net production rate
INPUT "Move in and move out cost (dollars) = ?",A(31)
IF A(31)=0 THEN 1780
IF (A(27)>1) AND (A(30)<>0) THEN 1800
IF A(31)=0 THEN 1960
GOSUB 1830
GOTO 1960
!
! Subroutine for entering area & yield
!
INPUT "Cutting unit area (acres) = ?",A(23)
IF A(23)<>0 THEN 1890
GOSUB 2230
GOTO 1830
DISP "Yield per acre (";LWC$(A$);") = ";
INPUT A(24)
IF A(24)<>0 THEN 1940
GOSUB 2230
GOTO 1890
RETURN
!
Z5=1      ! flag to print production data
GOTO 2290
B$=""
DISP "Average volume per piece as bucked (";LWC$(A$);") = ";
```

```
2000 INPUT A(25)
2010 IF A(25)<>0 THEN 2040
2020 GOSUB 2230
2030 GOTO 1990
2040 INPUT "Percent defect in pieces as yarded = ?",A(26)
2050 INPUT "Number of yarding roads in unit = ?",A(27)
2060 IF A(27)<>0 THEN 2090
2070 GOSUB 2230
2080 GOTO 2050
2090 INPUT "Average number of pieces per turn = ?",A(28)
2100 IF A(28)<>0 THEN 2130
2110 GOSUB 2230
2120 GOTO 2090
2130 INPUT "Average number of turns per hour = ?",A(29)
2140 IF A(29)<>0 THEN 2170
2150 GOSUB 2230
2160 GOTO 2130
2170 IF A(27)<=1 THEN 2190
2180 INPUT "Time per road change (hours) = ?",A(30)
2190 INPUT "Move in and move out cost (dollars) = ?",A(31)
2200 IF (A(27)>1) AND (A(30)<>0) OR (A(31)<>0) THEN GOSUB 1850
2210 GOTO 2290
2220 !
2230 ! routine to warn against input of 0 for variable value
2240 BEEP
2250 DISP "The value of 0 may not be entered for this variable! It must be re-en
tered."
2260 WAIT 5000
2270 RETURN
2280 !
2290 IF A(31)<>0 THEN 2320
2300 Z7(1)=Z7(2)=0      ! move cost
2310 GOTO 2330
2320 Z7(1)=Z7(2)=A(31)/A(23)/A(24)      ! move cost
2330 INPUT "Enter identifier (25 characters maximum)",C$
2340 IF LEN(C$)<=25 THEN 2380
2350 BEEP
2360 INPUT "25 characters maximum! Try again: enter identifier.",C$
2370 GOTO 2340
2380 D$=C$
2390 MAT B=A    ! new values = base values
2400 MAT D=C     ! new values = base values
2410 FOR X=1 TO U
2420 C(X,5)=C(X,1)*(100-C(X,2))/100      ! depreciable value
2430 C(X,6)=C(X,5)/C(X,3)      ! equipment depreciation
2440 M1=M1+C(X,4)*C(X,6)/(A(7)*A(8)*100)      ! total repairs & maintenance cost
2450 NEXT X
2460 !
2470 ! Routine to caluculate production rate and costs
2480 !
2490 B(33)=(D+A*(B(5)+B(6))/100)/B(7)/B(8)      ! ownership cost
2500 L=R=T=0
2510 IF (B(13)=0) OR (B(14)=0) THEN 2530
```

```
0 L=B(13)/B(14)
0 IF (B(15)=0) OR (B(16)=0) THEN 2550
0 R=B(15)/B(16)
0 IF (B(17)=0) OR (B(18)=0) THEN 2570
0 T=B(17)/B(18)
0 Q=(1+B(22)/100)*(B(19)*(1+B(20)/100+B(21)/B(2
0 B(34)=M1+B(9)*B(10)+B(11)*B(5)*B(12)/100+L+R+T+Q       ! operating cost
0 B(35)=B(33)+B(34)      ! machine rate
0 IF (B(30)=0) OR (B(27)<=1) THEN 2630
0 Z8(2)=(B(27)-1)*B(30)*B(35)/B(23)/B(24       ! setting change cost
0 GOTO 2640
0 Z8(2)=0      ! setting change cost
0 IF B(31)=0 THEN 2670
0 Z7(2)=B(31)/B(23)/B(24)      ! move cost
0 GOTO 2680
0 Z7(2)=0      ! move cost
0 IF Z5=1 THEN 2700
0 B(36)=B(25)*B(22)*B(29)      ! gross prod. rate if prod. rate unknown
0 B(37)=B(36)*(100-B(26))/100      ! net production rate
0 B(38)=B(35)/B(36)+Z7(2)+Z8(2)      ! gross yarding cost
0 B(39)=B(35)/B(37)+(Z7(2)+Z8(2))/(100-B(26))/100)      ! net yarding cost
0 IF P=1 THEN 5210  ! return to VARIABLE CHANGES routine
0 MAT A=B
0 Z7(1)=Z7(2)
0 Z8(1)=Z8(2)
0 IF C$="" THEN 2800
0 IMAGE "Values are for ",18A,/
0 PRINT USING 2780;C$
0 IMAGE /,"OWNERSHIP COST = $",4D.DD,"/HOUR"
0 PRINT USING 2800;A(33)
0 IMAGE "OPERATING COST = $",4D.DD,"/HOUR"
0 PRINT USING 2820;A(34)
0 PRINT SPA(17),"-------------"
0 IMAGE "MACHINE RATE =    $",4D.DD,"/HOUR"
0 PRINT USING 2850;A(35)
0 IF (A(26)<>0) OR (B(26)<>0) THEN 2990
0 IMAGE /,"PRODUCTION RATE =",4D.DDX,5A,"/HOUR",/
0 PRINT USING 2880;A(36),A$
0 IF (A(30)=0) OR (A(27)=1) THEN 2930      ! ie, no setting change time
0 IMAGE "ROAD CHANGE COST = $",3D.DD,"/",5A
0 PRINT USING 2910;Z8(1),A$
0 IF A(31)=0 THEN 2960
0 IMAGE "MOVE IN AND OUT COST =   $",3D.DD,"/",5A
0 PRINT USING 2940;Z7(1),A$
0 IMAGE /,/,"YARDING COST = $",4D.DD,"/",5A
0 PRINT USING 2960;A(38),A$
0 GOTO 3210
0 IMAGE /,"GROSS PRODUCTION RATE =",4D.DDX,5A,"/HOUR"
0 PRINT USING 2990;A(36),A$
0 IMAGE /,"NET PRODUCTION RATE =   ",4D.DDX,5A,"/HOUR",/
0 PRINT USING 3010;A(37),A$
0 IF (A(30)=0) OR (A(27)=1) THEN 3060
0 IMAGE "GROSS ROAD CHANGE COST =    $",3D.DD,"/",5A
```

```
3050 PRINT USING 3040;Z8(L),A$
3060 IF A(31)=0 THEN 3090
3070 IMAGE "GROSS MOVE IN AND OUT COST = $",3D.DD,"/",5A
3080 PRINT USING 3070;Z7(L),A$
3090 IF (A(30)=0) OR (A(27)=1) THEN 3120
3100 IMAGE /,"NET ROAD CHANGE COST =    $",3D.DD,"/",5A
3110 PRINT USING 3100;Z8(L)/(100-A(26))*100,A$
3120 IF A(31)=0 THEN 3170
3130 IF (A(30)<>0) AND (A(27)<>1) THEN 3150
3140 PRINT
3150 IMAGE "NET MOVE IN AND OUT COST = $",3D.DD,"/",5A
3160 PRINT USING 3150;Z7(L)/(100-A(26))*100,A$
3170 IMAGE /,/,"GROSS YARDING COST = $",4D.DD,"/",5A
3180 PRINT USING 3170;A(38),A$
3190 IMAGE /,"NET YARDING COST =    $",4D.DD,"/",5A
3200 PRINT USING 3190;A(39),A$
3210 IF P1=16 THEN 3230
3220 PRINT USING "/,/,/,/'
3230 PAUSE
3240 GOTO 3230
3250 !
3260 ! ********** KEY 0 (VARIABLE CHANGES) **********
3270 !
3280 PRINTER IS 16
3290 PRINT "VARIABLE CHANGES Routine",LIN(2)
3300 PRINTER IS P1
3310 B$=""
3320 F=0
3330 INPUT "The number of the variable to be changed = ?",N
3340 FOR X=1 TO 15
3350 READ B      ! read data from statement 65
3360 IF N<>B THEN 3390
3370 F=1
3380 GOTO 3400
3390 NEXT X
3400 RESTORE 130
3410 IF Z5=0 THEN 3470
3420 IF (N<>25) AND (N<>28) AND (N<>29) THEN 3470
3430 BEEP
3440 DISP "This variable cannot be changed in the 'known production' rate mode!"
3450 WAIT 6000
3460 GOTO 3320
3470 IF (N<=31) AND (N>0) THEN 3520
3480 BEEP
3490 INPUT "Variables are numbered 1-31! Try again: number of the variable to be
 changed = ?",N
3500 F=0
3510 GOTO 3340
3520 IF N>4 THEN 4020
3530 INPUT "For what piece (#) of equipment ?",N1
3540 IF (N1<=9) AND (N>0) THEN 3580
3550 BEEP
```

```
0 INPUT "Equipment pieces are numbered 1-9! Try again: for what piece (#) of
ipment ?",N1
0 GOTO 3540
0 IF N1<=U THEN 3770       ! see if a new piece is to be added
0 IF N1-U=1 THEN 3640      ! see if new piece # follows last piece #
0 BEEP
0 FIXED 0
0 DISP "Note: the piece # you selected is changed to";U+1;". Press CONT to pr
de."
0 PAUSE
0 N1=U=U+1
0 IF N1<6 THEN 3690
0 BEEP
0 DISP "Screen output may be incomplete for VARIABLE CHANGES & PRINT ANALYSIS
utines!"
0 WAIT 7000
0 IF N<>1 THEN 3890
0 FIXED 0
0 DISP "Equipment identifier (30 characters maximum) for piece #";N1;"= ";
0 INPUT G$(N1)
0 IF LEN(G$(N1))<=30 THEN 3890
0 BEEP
0 INPUT "30 characters maximum!  Try again: enter equipment identifier.",G$(N

0 GOTO 3730
0 IF N<>1 THEN 3890
0 IF (N1<=M) AND (D(N1,1)=0) THEN 3890
0 ! Routine to allow equipment to be deleted
0 !
0 INPUT "Do you want to delete this piece of equipment? (YES or NO)",B$
0 IF B$[1,1]="N" THEN 3890
0 IF B$[1,1]<>"Y" THEN 3810
0 D(N1,1)=D(N1,2)=D(N1,3)=D(N1,4)=0
0 IF U<=M THEN 4480       ! see if deleted piece was previously an added piece
0 U=U-1       ! reduce number of pieces by one
0 GOTO 4480
0 !
0 IF (D(N1,1)<>0) OR (D(N1,2)<>0) OR (D(N1,3)<>0) OR (D(N1,4)<>0) THEN 3920
0 GOSUB 4670
0 GOTO 4480
0 FIXED 0
0 DISP "BASE VALUE =";C(N1,N);"    LAST VALUE =";D(N1,N);"    NEW VALUE = ";
0 INPUT J
0 IF (F<>0) AND (J=0) THEN 3980
0 D(N1,N)=J
0 GOTO 4480
0 BEEP
0 DISP "The value of 0 may not be entered for this variable!  It must be re-e
ered."
0 WAIT 6000
0 GOTO 3920
0 FIXED 2
0 DISP "BASE VALUE =";A(N);"    LAST VALUE =";B(N);"    NEW VALUE = ";
```

```
4040 INPUT J
4050 IF (F<>0) AND (J=0) THEN 4080
4060 B(N)=J
4070 GOTO 4160
4080 IF (N<>23) AND (N<>24) THEN 4120
4090 IF (B(27)>1) AND (B(30)<>0) THEN 4120
4100 IF B(31)<>0 THEN 4120
4110 GOTO 4060
4120 BEEP
4130 DISP "A value of 0 may not be entered for this variable!  It must be re-ent
ered."
4140 WAIT 6000
4150 GOTO 4020
4160 IF (N<>27) AND (N<>30) AND (N<>31) THEN 4480
4170 IF N<>27 THEN 4240
4180 IF (B(30)<>0) OR (B(27)<=1) THEN 4320
4190 INPUT "Time per setting change (hours) = ?",B(30)
4200 IF B(30)>0 THEN 4320
4210 BEEP
4220 INPUT "You must enter a value greater than 0!  Try again: time per setting
chg (hr) = ?",B(30)
4230 GOTO 4200
4240 IF N<>30 THEN 4320
4250 IF (B(27)>1) OR (B(30)=0) THEN 4320
4260 INPUT "Number of settings in unit = ?",B(27)
4270 IF B(27)>1 THEN 4320
4280 BEEP
4290 INPUT "A value of 2 or more must be entered!  Try again: number of settings
 in unit = ?",B(27)
4300 GOTO 4270
4310 !
4320 ! Routine to supply values for area & yield if needed
4330 !
4340 IF (B(27)<=1) OR (B(30)=0) THEN 4480
4350 IF (B(23)<>0) AND (B(24)<>0) THEN 4480
4360 INPUT "Cutting unit area (acres) = ?",B(23)
4370 IF B(23)>0 THEN 4410
4380 BEEP
4390 INPUT "You must enter a value greater than 0!  Try again: cutting unit area
 (acres) = ?",B(23)
4400 GOTO 1884
4410 DISP "Yield per acre (";LWC$(A$);") = ";
4420 INPUT B(24)
4430 IF B(24)>0 THEN 4480
4440 BEEP
4450 INPUT "You must enter a value greater than 0!  Try again: yield per acre =
?",B(24)
4460 GOTO 4430
4470 !
4480 INPUT "Any more variable changes desired ? (YES or NO)",B$
4490 IF B$[1,1]="Y" THEN 3300
4500 IF D$[1,1]<>"N" THEN 4480
4510 B$=""
```

```
0 IF (B(27)>1) AND (B(30)<>0) THEN 4540
0 IF B(31)=0 THEN 5040
0 IF (B(23)<>0) AND (B(24)<>0) THEN 5040
0 INPUT "Cutting unit area (acres) = ?",B(23)
0 IF B(23)>0 THEN 4600
0 BEEP
0 INPUT "You must enter a value greater than 0!  Try again: cutting unit area
cres) = ?",B(23)
0 GOTO 4560
0 DISP "Yield per acre (";LWC$(A$);") = ";
0 INPUT B(24)
0 IF B(24)>0 THEN 5040
0 BEEP
0 INPUT "You must enter a value greater than 0!  Try again: yield per acre =
B(24)
0 GOTO 4620
0 !
0 ! Routine to insure that variables # 1,2,3 & 4 have all been given values
0 ! when a new piece of equipment is added
0 !
0 FIXED 0
0 FOR X=1 TO 4
0 ON N GOTO 4730,4740,4750,4760
0 ON X GOTO 4770,4890,4920,4990
0 ON X GOTO 4890,4770,4920,4990
0 ON X GOTO 4920,4770,4890,4990
0 ON X GOTO 4990,4770,4890,4920
0 IF X<=M THEN 4840
0 DISP "Equipment identifier (30 characters maximum) for piece #";N1;"= ";
0 INPUT G$(N1)
0 IF LEN(G$(N1))<=30 THEN 4840
0 BEEP
0 INPUT "30 characters maximum!  Try again: enter equipment identifier.",G$(N

0 GOTO 4800
4 DISP "For piece #";N1;":  Cost of ";G$(N1);" (dollars) = ";
5 INPUT D(N1,1)
6 IF D(N1,1)<>0 THEN 5010
7 GOSUB 3760
8 GOTO 4840
9 DISP "For piece #";N1;":  Residual value (percent of equipment cost) = ";
0 INPUT D(N1,2)
1 GOTO 5010
2 DISP "For piece #";N1;":  Depreciation period (years) = ";
3 INPUT D(N1,3)
4 IF D(N1,3)<>0 THEN 5010
5 BEEP
6 DISP "The value of 0 may not be entered for this variable!  It must be re-e
ered."
7 WAIT 6000
8 GOTO 4920
9 DISP "For piece #";N1;":  Repairs and maintenance (percent of equipment dep
cation) = ";
```

```
5000 INPUT D(N1,4)
5010 NEXT X
5020 RETURN
5030 !
5040 A=D=M1=0
5050 K=1
5060 INPUT "Enter identifier for NEW VALUES (25 characters maximum).",D$
5070 IF LEN(D$)<=25 THEN 5110
5080 BEEP
5090 INPUT "25 characters maximum! Try again: enter identifier for NEW VALUES."
D$
5100 GOTO 5010
5110 INPUT "Enter a new heading for all output (70 characters maximum).".H$
5120 IF LEN(H$)<=70 THEN 5180
5130 BEEP
5140 FIXED 0
5150 DISP "Sorry, you're";LEN(H$)-70;"characters over the limit of 70!  Try agai
n: heading = ";
5160 INPUT H$
5170 GOTO 5120
5180 FIXED 2
5190 P=1
5200 GOTO 930     ! calculate basis of ownership cost
5210 PAUSE
5220 GOTO 5210
5230 !
5240 ! ********** KEY 2 (PART 1) **********
5250 !
5260 S=1
5270 !
5280 ! ********** KEY 1 (PRINT ANALYSIS) **********
5290 !
5300 IF P1<>0 THEN 5400
5310 IF H$="" THEN 5330
5320 PRINT H$,LIN(2)
5330 IF (C$="") AND (D$="') THEN 5380
5340 IMAGE "ANALYSIS OF VARIABLE CHANGES              BASE VALUES = ",25A,/,40X,"N
EW VALUES  = ",25A,/
5350 PRINT USING 5340;C$,D$
5360 PRINT TAB(56),"BASE     NEW     PERCENT"
5370 GOTO 5470
5380 PRINT USING "28A,/,55X,4A,5X,3A,5X,7A";"ANALYSIS OF VARIABLE CHANGES","BASE
","NEW","PERCENT"
5390 GOTO 5470
5400 IF H$="" THEN 5420
5410 PRINT H$,LIN(2)
5420 IF (C$="") AND (D$="') THEN 5460
5430 IMAGE "ANALYSIS OF VARIABLE CHANGES              BASE VALUES = ",25A,/,"(PART
 1)",32X,"NEW VALUES  = ",18A,/
5440 PRINT USING 5430;C$,D$
5450 GOTO 5360
5460 PRINT USING "28A,/,8A,31X,4A,10X,3A,6X,7A";"ANALYSIS OF VARIABLE CHANGES","
(PART 1)","BASE","NEW","PERCENT"
```

```
PRINT TAB(55),"VALUES     VALUES    CHANGE",LIN(1)
IF U>1 THEN 5770
E=1
GOSUB 5670
IMAGE "1  COST OF ",30A,"  (DOLLARS)",8D,10D,6D.D
PRINT USING 5510;LWC$(G$(1)),C(1,1),D(1,1),W
E=2
GOSUB 5670
IMAGE "2  RESIDUAL (PERCENT OF EQUIPMENT COST)",21D,10D,6D.D
PRINT USING 5550;C(1,2),D(1,2),W
E=3
GOSUB 5670
IMAGE "3  DEPRECIATION PERIOD (YEARS)",32D,10D,6D.D
PRINT USING 5590;C(1,3),D(1,3),W
E=4
GOSUB 5670
IMAGE "4  REPAIRS AND MAINTENANCE (PERCENT OF DEPRECIATION)",8D,10D,6D.D
PRINT USING 5630;C(1,4),D(1,4),W
GOTO 6300
!
! subroutine to compute % change
IF C(1,E)<>0 THEN 5740
IF D(1,E)<>0 THEN 5720
W=0
RETURN
W=100
RETURN
W=100*(D(1,E)-C(1,E))/C(1,E)
RETURN
!
IMAGE "1 #1 COST OF ",30A,"(DOLLARS)",8D,10D,6D.D
PRINT USING 5770;LWC$(G$(1)),C(1,1),D(1,1),100*(D(1,1)-C(1,1))/C(1,1)
FOR X=2 TO U
IF C(X,1)>0 THEN 5860
IF D(X,1)=0 THEN 5840
W=100
GOTO 5870
W=0
GOTO 5870
W=100*(D(X,1)-C(X,1))/C(X,1)
IMAGE "  #",D," COST OF ",30A,"(DOLLARS)",8D,10D,6D.D
PRINT USING 5870;X,LWC$(G$(X)),C(X,1),D(X,1),W
NEXT X
IMAGE "2 #1 RESIDUAL (PERCENT OF EQUIPMENT COST)",19D,10D,6D.D
PRINT USING 5900;C(1,2),D(1,2),100*(D(1,2)-C(1,2))/C(1,2)
FOR X=2 TO U
IF C(X,2)>0 THEN 5990
IF D(X,2)=0 THEN 5970
W=100
GOTO 6000
W=0
GOTO 6000
W=100*(D(X,2)-C(X,2))/C(X,2)
```

```
6000 IMAGE "  #",D," RESIDUAL (PERCENT OF EQUIPMENT COST)",19D,10D,6D.D
6010 PRINT USING 6000;X,C(X,2),D(X,2),W
6020 NEXT X
6030 IMAGE "3 #1 DEPRECIATION PERIOD (YEARS)",28D,10D,6D.D
6040 PRINT USING 6030;C(1,3),D(1,3),100*(D(1,3)-C(1,3))/C(1,3)
6050 FOR X=2 TO U
6060 IF C(X,3)>0 THEN 6120
6070 IF D(X,3)=0 THEN 6100
6080 W=100
6090 GOTO 6130
6100 W=0
6110 GOTO 6130
6120 W=100*(D(X,3)-C(X,3))/C(X,3)
6130 IMAGE "  #",D," DEPRECIATION PERIOD (YEARS)",28D,10D,6D.D
6140 PRINT USING 6130;X,C(X,3),D(X,3),W
6150 NEXT X
6160 IMAGE "4 #1 REPAIRS & MAINTENANCE (PERCENT OF DEPRECIATION)",8D,10D,6D.D
6170 PRINT USING 6160;C(1,4),D(1,4),100*(D(1,4)-C(1,4))/C(1,4)
6180 FOR X=2 TO U
6190 IF C(X,4)>0 THEN 6250
6200 IF D(X,4)=0 THEN 6230
6210 W=100
6220 GOTO 6260
6230 W=0
6240 GOTO 6260
6250 W=100*(D(X,4)-C(X,4))/C(X,4)
6260 IMAGE "  #",D," REPAIRS & MAINTENANCE (PERCENT OF DEPRECIATION)",8D,10D,6D
D
6270 PRINT USING 6260;X,C(X,4),D(X,4),W
6280 NEXT X
6290 H=1
6300 FOR X=5 TO 39
6310 IF A(X)<>0 THEN 6370
6320 IF B(X)<>0 THEN 6350
6330 E(X)=0
6340 GOTO 6380
6350 E(X)=100
6360 GOTO 6380
6370 E(X)=100*(B(X)-A(X))/A(X)
6380 NEXT X
6390 IF H1=1 THEN 6960
6400 IMAGE "5  ANNUAL INTEREST RATE (PERCENT)",24D.DD,7D.DD,6D.D
6410 PRINT USING 6400;A(5),B(5),E(5)
6420 IMAGE "6  TAX,LICENSE,INSURANCE, AND STORAGE (PERCENT)",10D.DD,7D.DD,6D.D
6430 PRINT USING 6420;A(6),B(6),E(6)
6440 IMAGE "7  OPERATING SEASON (DAYS WORKED/YEAR)",22D,10D,6D.D
6450 PRINT USING 6440;A(7),B(7),E(7)
6460 IMAGE "8  OPERATING TIME PER DAY (HOURS)",25D.D,8D.D,6D.D
6470 PRINT USING 6460;A(8),B(8),E(8)
6480 IMAGE "9  FUEL CONSUMPTION (GALLONS/HOUR)",23D.DD,7D.DD,6D.D
6490 PRINT USING 6480;A(9),B(9),E(9)
6500 IMAGE "10 FUEL COST (DOLLARS/GALLON)",28D.DD,7D.DD,6D.D
6510 PRINT USING 6500;A(10),B(10),E(10)
```

```
IMAGE "11 OIL AND LUBE (PERCENT OF FUEL CONSUMPTION)",15D,10D,6D.D
PRINT USING 6520;A(11),B(11),E(11)
IMAGE "12 OIL AND LUBE COST (DOLLARS/GALLON)",20D.DD,7D.DD,6D.D
PRINT USING 6540;A(12),B(12),E(12)
IMAGE "13 LINE COST (DOLLARS)",38D,10D,6D.D
PRINT USING 6560;A(13),B(13),E(13)
IMAGE "14 LINE LIFE (HOURS)",40D,10D,6D.D
PRINT USING 6580;A(14),B(14),E(14)
IMAGE "15 RIGGING COST (DOLLARS)",35D,10D,6D.D
PRINT USING 6600;A(15),B(15),E(15)
IMAGE "16 RIGGING LIFE (HOURS)",37D,10D,6D.D
PRINT USING 6620;A(16),B(16),E(16)
IMAGE "17 TIRE OR TRACK REPLACEMENT COST (DOLLARS)",17D,10D,6D.D
PRINT USING 6640;A(17),B(17),E(17)
IMAGE "18 TIRE OR TRACK LIFE (HOURS)",31D,10D,6D.D
PRINT USING 6660;A(18),B(18),E(18)
IMAGE "19 TOTAL CREW WAGE (DOLLARS/HOUR)",24D.DD,7D.DD,6D.D
PRINT USING 6680;A(19),B(19),E(19)
IMAGE "20 FRINGE BENEFITS (PERCENT OF TOTAL CREW WAGE)",13D,10D,6D.D
PRINT USING 6700;A(20),B(20),E(20)
IMAGE "21 TRAVEL TIME PER DAY (HOURS)",27D.DD,7D.DD,6D.D
PRINT USING 6720;A(21),B(21),E(21)
IMAGE "22 SUPERVISION AND OVERHEAD (PERCENT OF DIRECT LABOR)",7D,10D,6D.D
PRINT USING 6740;A(22),B(22),E(22)
IF S=1 THEN 6780
IF P1=0 THEN 6930
PRINT LIN(4)
IF P1=0 THEN 6810
PRINT "****** PRESS KEY 3 ('PART 2') TO DISPLAY REMAINDER OF ANALYSIS *****

S=0
PAUSE
GOTO 6810
!
! ********** KEY 3 (PRINT ANALYSIS - PART 2) **********
!
S=2
IF H$="" THEN 6900
PRINT H$,LIN(2)
IMAGE "ANALYSIS OF VARIABLE CHANGES                BASE VALUES = ",25A,/,"(PART
),32X,"NEW VALUES  = ",25A,/
PRINT USING 6900;C$,D$
PRINT TAB(56),"BASE      NEW      PERCENT",LIN(1),TAB(55),"VALUES    VALUES
HNGE",LIN(1)
IF H=1 THEN 6960
H1=1
GOTO 6290
H=H1=0
IF (P1=16) OR (S=2) THEN 6990
PRINT LIN(2)
S=0
IF (Z7(1)=0) AND (Z7(2)=0) AND (Z8(1)=0) AND (Z8(2)=0) THEN 7050
IMAGE "23 CUTTING UNIT AREA (ACRES)",32D,10D,6D.D
```

```
7020 PRINT USING 7010;A(23),B(23),E(23)
7030 IMAGE "24 YIELD PER ACRE (",5A,")",32D.DD,7D.DD,6D.D
7040 PRINT USING 7030;A$,A(24),B(24),E(24)
7050 IF Z5=1 THEN 7080      ! known production rate
7060 IMAGE "25 AVG. VOLUME/PIECE AS BUCKED ("5A,")",19D.DD,7D.DD,6D.D
7070 PRINT USING 7060;A$,A(25),B(25),E(25)
7080 IMAGE "26 DEFECT IN PIECES AS YARDED (PERCENT)",18D.DD,7D.DD,6D.D
7090 PRINT USING 7080;A(26),B(26),E(26)
7100 IF (Z5=0) OR (A(27)=0) THEN 7120        !A(27)=0 only if known p.r. includes
7110 IF (A(27)<=1) AND (B(27)<=1) THEN 7140                !setting change time
7120 IMAGE "27 NUMBER OF YARDING ROADS IN UNIT",26D,10D,6D.D
7130 PRINT USING 7120;A(27),B(27),E(27)
7140 IF Z5=1 THEN 7190      ! known production rate
7150 IMAGE "28 AVERAGE NUMBER OF PIECES PER TURN",21D.DD,7D.DD,6D.D
7160 PRINT USING 7150;A(28),B(28),E(28)
7170 IMAGE "29 AVERAGE NUMBER OF TURNS PER HOUR",22D.DD,7D.DD,6D.D
7180 PRINT USING 7170;A(29),B(29),E(29)
7190 IF (Z5=0) OR (A(27)=0) THEN 7210
7200 IF (A(30)=0) AND (B(30)=0) THEN 7230
7210 IMAGE "30 TIME PER ROAD CHANGE (HOURS)",26D.DD,7D.DD,6D.D
7220 PRINT USING 7210;A(30),B(30),E(30)
7230 IMAGE "31 MOVE IN AND MOVE OUT COST (DOLLARS)",22D,10D,6D.D
7240 PRINT USING 7230;A(31),B(31),E(31)
7250 PRINT
7260 PRINT
7270 IMAGE /,/,"OWNERSHIP COST (DOLLARS/HOUR)",28D.DD,7D.DD,6D.D
7280 PRINT USING 7270;A(33),B(33),E(33)
7290 IMAGE "OPERATING COST (DOLLARS/HOUR)",28D.DD,7D.DD,6D.D
7300 PRINT USING 7290;A(34),B(34),E(34)
7310 PRINT SPA(54),"------    ------"
7320 IMAGE "MACHINE RATE (DOLLARS/HOUR)",30D.DD,7D.DD,6D.D
7330 PRINT USING 7320;A(35),B(35),E(35)
7340 IF (A(26)<>0) OR (B(26)<>0) THEN 7610
7350 IMAGE /,"PRODUCTION RATE (",5A,"/HOUR)",29D.DD,7D.DD,6D.D
7360 PRINT USING 7350;A$,A(36),B(36),E(36)
7370 IF (A(30)<>0) AND (A(27)>1) THEN 7390
7380 IF (B(30)=0) OR (B(27)<=1) THEN 7480
7390 IMAGE "ROAD CHANGE COST (DOLLARS/",5A,")",25D.DD,7D.DD,6D.D
7400 IF Z8(1)<>0 THEN 7460
7410 IF Z8(2)=0 THEN 7440
7420 W=100
7430 GOTO 7470
7440 W=0
7450 GOTO 7470
7460 W=(Z8(2)-Z8(1))/Z8(1)*100
7470 PRINT USING 7390;A$,Z8(1),Z8(2),W
7480 IF (A(31)=0) AND (B(31)=0) THEN 7580
7490 IMAGE "MOVE IN AND OUT COST (DOLLARS/",5A,")",21D.DD,7D.DD,6D.D
7500 IF Z7(1)<>0 THEN 7560
7510 IF Z7(2)=0 THEN 7540
7520 W=100
7530 GOTO 7570
7540 W=0
```

```
GOTO 7570
W=(Z7(2)-Z7(1))/Z7(1)*100
PRINT USING 7490;A$,Z7(1),Z7(2),W
IMAGE /,/,"YARDING COST (DOLLARS/",5A,")",29D.DD,7D.DD,6D.D
PRINT USING 7580;A$,A(38),B(38),E(38)
GOTO 7990
IMAGE /,"GROSS PRODUCTION RATE (",5A,"/HOUR)",23D.DD,7D.DD,6D.D
PRINT USING 7610;A$,A(36),B(36),E(36)
IMAGE /,"NET PRODUCTION RATE (",5A,"/HOUR)",25D.DD,7D.DD,6D.D
PRINT USING 7630;A$,A(37),B(37),E(37)
IF (A(30)<>0) AND (A(27)>1) THEN 7670
IF (B(30)=0) OR (B(27)<=1) THEN 7760
IMAGE "GROSS ROAD CHANGE COST (DOLLARS/",5A,")",19D.DD,7D.DD,6D.D
IF Z8(1)<>0 THEN 7740
IF Z8(2)=0 THEN 7720
W=100
GOTO 7750
W=0
GOTO 7750
W=(Z8(2)-Z8(1))/Z8(1)*100
PRINT USING 7670;A$,Z8(1),Z8(2),W
IF (A(31)=0) AND (B(31)=0) THEN 7860
IMAGE "GROSS MOVE IN AND OUT COST (DOLLARS/",5A,")",15D.DD,7D.DD,6D.D
IF Z7(1)<>0 THEN 7840
IF Z7(2)=0 THEN 7820
W1=100
GOTO 7850
W1=0
GOTO 7850
W1=(Z7(2)-Z7(1))/Z7(1)*100
PRINT USING 7770;A$,Z7(1),Z7(2),W1
IF (A(30)<>0) AND (A(27)>1) THEN 7880
IF (B(30)=0) OR (B(27)<=1) THEN 7900
IMAGE /,"NET ROAD CHANGE COST (DOLLARS/",5A,")",21D.DD,7D.DD,6D.D
PRINT USING 7880;A$,Z8(1)/(100-A(26))*100,Z8(2)/(100-A(26))*100,W
IF (A(31)=0) AND (B(31)=0) THEN 7950
IF (A(30)<>0) AND (B(30)<>0) AND (A(27)>1) AND (B(27)>1) THEN 7930
PRINT
IMAGE "NET MOVE IN AND OUT COST (DOLLARS/",5A,")",17D.DD,7D.DD,6D.D
PRINT USING 7930;A$,Z7(1)/(100-A(26))*100,Z7(2)/(100-A(26))*100,W1
IMAGE /,/,"GROSS YARDING COST (DOLLARS/",5A,")",23D.DD,7D.DD,6D.D
PRINT USING 7950;A$,A(38),B(38),E(38)
IMAGE /,"NET YARDING COST (DOLLARS/",5A,")",25D.DD,7D.DD,6D.D
PRINT USING 7970;A$,A(39),B(39),E(39)
IF P1=16 THEN 8010
PRINT USING "/,/,/,/"
PAUSE
GOTO 8010
!
! ********** KEYS 11,12,13,14 & 15 (CHANGE OWNERSHIP COST, OPERATING COST,
!            MACHINE RATE, GROSS VOL/HR & NET VOL/HR) **********
!
N=33              ! key 11
```

```
8080 E$="OWNERSHIP COST"
8090 GOTO 8250
8100 N=34                    ! key 12
8110 E$="OPERATING COST"
8120 GOTO 8250
8130 N=35                    ! key 13
8140 E$="MACHINE RATE"
8150 GOTO 8250
8160 N=36                    ! key 14
8170 IF Z5=0 THEN 8200
8180 E$="VOLUME/HR"
8190 GOTO 8250
8200 E$="GROSS VOLUME/HR"
8210 GOTO 8250
8220 IF Z5=1 THEN 8160       ! key 15
8230 N=37
8240 E$="NET VOLUME/HR"
8250 FIXED 2
8260 PRINTER IS 16
8270 PRINT USING "6A,X,15A,X,7A,/,/";"CHANGE",E$,"Routine"
8280 PRINTER IS P1
8290 DISP E$;":  BASE VALUE =";A(N);"    LAST VALUE =";B(N);"    NEW VALUE = ";
8300 INPUT B(N)
8310 INPUT "Enter identifier for NEW VALUES (25 characters maximum)",F$
8320 IF F$="" THEN 8380
8330 IF LEN(F$)<=25 THEN 8370
8340 BEEP
8350 INPUT "25 characters maximum! Try again: enter identifier for NEW VALUES."
F$
8360 GOTO 8320
8370 D$=F$
8380 INPUT "Enter a new heading for all output (70 characters maximum).",H$
8390 IF LEN(H$)<=70 THEN 8460
8400 BEEP
8410 FIXED 0
8420 DISP "Sorry, you're";LEN(H$)-70;"characters over the limit of 70!  Try aga
n: heading = ";
8430 INPUT H$
8440 FIXED 2
8450 GOTO 8390
8460 K=1
8470 IF N=35 THEN 8490
8480 B(35)=B(33)+B(34)       ! machine rate
8490 IF (B(30)=0) OR (B(27)<=1) THEN 8520
8500 Z8(2)=(B(27)-1)*B(30)*B(35)/B(23)/B(24)      ! setting change cost
8510 GOTO 8530
8520 Z8(2)=0
8530 IF Z5=1 THEN 8570
8540 IF N=36 THEN 8580
8550 B(36)=B(25)*B(28)*B(29)      ! gross prod. rate if prod. rate unknown
8560 IF N=37 THEN 8580
8570 B(37)=B(36)*(100-B(26))/100      ! net production rate
8580 B(38)=B(35)/B(36)+Z7(2)+Z8(2)      ! gross yarding cost
```

```
B(39)=B(35)/B(37)+Z7(2)+Z8(2)         ! net yarding cost
IF H$="" THEN 8620
PRINT H$,LIN(2)
IF (C$="") AND (D$="") THEN 8660
IMAGE "ANALYSIS WITH NEW VALUE OF",14X,"BASE VALUES = ",25A, ,20A,20X,"NEW
ES =  ",25A,/
PRINT USING 8630;C$,E$,D$
GOTO 8680
IMAGE "ANALYSIS WITH NEW VALUE OF", ,20A
PRINT USING 8660;E$
PRINT SPA(55);"BASE";SPA(4);"NEW";SPA(4);"PERCENT";LIN(1);SPA(54);"VALUES";
4);"VALUES";SPA(3);"CHANGE"
FOR X=33 TO 39
IF A(X)<>0 THEN 8760
IF B(X)<>0 THEN 8740
E(X)=0
GOTO 8770
E(X)=100
GOTO 8770
E(X)=100*(B(X)-A(X))/A(X)
NEXT X
GOTO 7270
!
! ********** KEY 4 (NEW VALUES REPLACED BY BASE VALUES) **********
!
FOR X=5 TO 39
B(X)=A(X)
NEXT X
D$=C$
Z7(2)=Z7(1)
Z8(2)=Z8(1)
MAT D=C
U=M
PAUSE
GOTO 8900
!
! ********** KEY 20 (BASE VALUES REPLACED BY NEW VALUES) **********
!
FOR X=5 TO 39
A(X)=B(X)
NEXT X
C$=D$
Z7(1)=Z7(2)
Z8(1)=Z8(2)
!
! routine to remove any deleted pieces of equipment
!
FOR X=1 TO U
IF (D(X,1)=0) AND (D(X,2)=0) AND (D(X,3)=0) AND (D(X,4)=0) THEN 9080
NEXT X
GOTO 9230
U=U-1
D(X,1)=D(X+1,1)
```

```
9100 D(X,2)=D(X+1,2)
9110 D(X,3)=D(X+1,3)
9120 D(X,4)=D(X+1,4)
9130 G$(X)=G$(X+1)
9140 FOR X1=X+1 TO U
9150 D(X1,1)=D(X1+1,1)
9160 D(X1,2)=D(X1+1,2)
9170 D(X1,3)=D(X1+1,3)
9180 D(X1,4)=D(X1+1,4)
9190 NEXT X1
9200 D(X1,1)=D(X1,2)=D(X1,3)=D(X1,4)=0
9210 GOTO 9040
9220 !
9230 MAT C=D
9240 M=U
9250 PAUSE
9260 GOTO 9250
9270 !
9280 ! ********** KEY 6 (OUTPUT ON PRINTER) **********
9290 !
9300 P1=0
9310 GOTO 9360
9320 !
9330 ! ********** KEY 5 (OUTPUT ON PLOTTER) **********
9340 !
9350 P1=16
9360 PRINTER IS P1
9370 PAUSE
9380 GOTO 9370
9390 !
9400 ! ********** KEY 8 (PLOT ON SCREEN) **********
9410 !
9420 A7=1
9430 DISP "PLOT ON SCREEN"
9440 PAUSE
9450 GOTO 9440
9460 !
9470 ! ********** KEY 9 (PLOT ON PLOTTER) **********
9480 !
9490 A7=2
9500 DISP "PLOT ON PLOTTER  -  Plotter must be turned on."
9510 PAUSE
9520 GOTO 9510
9530 !
9540 ! ********** KEY 10 (AXES & PLOT) **********
9550 !
9560 A8=S2=0
9570 I=1
9580 IF A7=1 THEN 9680      ! plot on screen
9590 IF A7=0 THEN 10750     ! plot on plotter
9600 !
9610 ! plot on plotter routine
9620 !
```

```
PLOTTER IS "GRAPHICS'
PLOTTER IS 7,5,"9872A"              ! SET PLOTTER LIMITS TO 6.25 X 6.25 INCHES
PLOTTER 7,5 IS ON
GOTO 9720
!
! plot on screen routine
!
PLOTTER IS 13,"GRAPHICS"
GRAPHICS
IF A8=1 THEN 10800
!
! axes & plot
!
IF A7<>0 THEN 9780
GOTO 10750
IF (A(26)<>0) OR (B(26)<>0) THEN 9810
K3=1      ! flag to suppress 'net' or 'gross' label
GOTO 9890
INPUT "Do you want to plot gross rather that net values? (YES or NO)",B$
IF B$[1,1]="Y" THEN 9880
IF B$[1,1]<>"N" THEN 9810
K3=2      ! flag to print 'net' label
K1=37      ! net values will be plotted
K2=39
GOTO 9910
K3=3      ! flag to print 'gross' label
K1=36      ! gross values will be plotted
K2=38
B$=""
IF S2=1 THEN 10740
LOCATE 16,96,16,96
PEN 1
A5=2
A6=4
!
! routine to automatically caluclate ranges for horizontal & vertical axes
!
0 IF A(K1)>=B(K1) THEN 10030
0 A1=B(K1)
0 GOTO 10040
0 A1=A(K1)
0 IF A(K2)>=B(K2) THEN 10070
0 A2=B(K2)
0 GOTO 10110
0 A2=A(K2)
0 !
0 ! routine to round off axes values to nearest higher value of 10
0 !
0 IF A1 MOD 10<>0 THEN 10140
0 IF A2 MOD 10<>0 THEN 10160
0 GOTO 10170
0 A1=(A1 DIV 10+1)*10
0 GOTO 10120
```

```
10160 A2=(A2 DIV 10+1)*10
10170 FIXED 0
10180 IF B$[1,1]="Y" THEN 10280
10190 !
10200 DISP "Want to define range of prod. rate & yarding cost other than";A1;"&
;A2;" (YES/NO)";
10210 INPUT B$
10220 FIXED 2
10230 IF B$[1,1]="Y" THEN 10260
10240 IF B$[1,1]<>"N" THEN 10200
10250 GOTO 10280
10260 INPUT "Enter: maximum production rate (X-axis), maximum yarding cost (Y-a
is)",A1,A2
10270 GOTO 10110
10280 B$=""
10290 A9=A2*1.2
10300 SCALE 0,A1,0,A2
10310 AXES A1/10,A2/10,0,0
10320 LOCATE 0,100,0,100
10330 SCALE 0,A1/5*6.25,0,A2/5*6.25
10340 CSIZE 3
10350 DEG
10360 LDIR 0
10370 LORG 6
10380 FOR X=A1/5 TO A1/5*6 STEP A1/10     ! label horizontal axis
10390 MOVE X,A2*.8/5
10400 LABEL USING "DD";X-A1/5
10410 NEXT X
10420 LORG 8
10430 FOR X=A2/5 TO A2/5*6 STEP A2/10     ! label vertical axis
10440 MOVE A1*.8/5,X
10450 LABEL USING "DD";X-A2/5
10460 NEXT X
10470 LORG 1
10480 CSIZE 4
10490 MOVE A1/5*1.05,0
10500 ON K3 GOTO 10510,10540,10570
10510 IMAGE "   PRODUCTION RATE (",5A,"/HOUR)"
10520 LABEL USING 10510;A$
10530 GOTO 10590
10540 IMAGE " NET PRODUCTION RATE (",5A,"/HOUR)"
10550 LABEL USING 10540;A$
10560 GOTO 10590
10570 IMAGE "GROSS PRODUCTION RATE (",5A,"/HOUR)"
10580 LABEL USING 10570;A$
10590 LDIR 90
10600 MOVE A1*.03,A2/5*1
10610 ON K3 GOTO 10620,10650,10680
10620 IMAGE "   YARDING COST (DOLLARS/",5A,")"
10630 LABEL USING 10620;A$
10640 GOTO 10800
10650 IMAGE " NET YARDING COST (DOLLARS/",5A,")"
10660 LABEL USING 10650;A$
```

```
GOTO 10800
IMAGE "GROSS YARDING COST (DOLLARS/",5A,")"
LABEL USING 10680;A$
GOTO 10800
!
! plot
!
IF A7<>0 THEN 10770
DISP "You must press key 8 or key 9 first."
PAUSE
IF S2=1 THEN 10800
A8=1
GOTO 9580
LOCATE 0,100,0,100
SCALE 0,A1/5*6.25,0,A2/5*6.25
LOCATE 16,96,16,96
INPUT "Enter: 0 to plot BASE VALUES; 1 to plot NEW VALUES; 2 to plot
h",A3
!
! routine to set line type
!
A5=A5+2
IF A5<>10 THEN 10930
A6=A6+2
IF A6=10 THEN 11380
A5=2
GOTO 10870
LINE TYPE A5,A6
!
! routine to draw curve
!
A9=A9-A2*.04
IF S2=0 THEN 11000
GRAPHICS
IF A3=1 THEN 11300
!
! PLOT BASE VALUES
!
FOR X=A1 TO .5 STEP -.5
A4=Z7(1)+Z8(1)+A(35)/X
PLOT X+A1/5,A4+A2/5
NEXT X
!
! routine to draw lines & label
!
PENUP
MOVE A(K1)+A1/5,A2/5
PLOT A(K1)+A1/5,A(K2)+A2/5,-1
PLOT A1/5,A(K2)+A2/5,2
CSIZE 3
MOVE A1*.65,A9
DRAW A1*.81,A9
MOVE A1*.85,A9
```

```
11190 LORG 2
11200 LDIR 0
11210 LINE TYPE 1
11220 LABEL C$
11230 IF (A(K1)<>B(K1)) OR (A(K2)<>B(K2)) OR (A3<>2) THEN 11280
11240 A9=A9-A2*.04
11250 MOVE A1*.81,A9
11260 LABEL "& ";D$
11270 GOTO 11670
11280 IF A3=0 THEN 11670
11290 !
11300 ! PLOT NEW VALUES
11310 !
11320 ! routine to set line type
11330 !
11340 A5=A5+2
11350 IF A5<>10 THEN 11420
11360 A6=A6+2
11370 IF A6<>10 THEN 5690
11380 DISP "No more plots allowed!"
11390 PAUSE
11400 A5=2
11410 GOTO 11340
11420 IF A3=1 THEN 11480
11430 LINE TYPE A5,A6
11440 !
11450 ! routine to draw curve
11460 !
11470 A9=A9-A2*.04
11480 FOR X=A1 TO .5 STEP -.5
11490 A4=Z7(2)+Z8(2)+B(35)/X
11500 PLOT X+A1/5,A4+A2/5
11510 NEXT X
11520 !
11530 ! routine to draw lines & label
11540 !
11550 PENUP
11560 MOVE B(K1)+A1/5,A2/5
11570 PLOT B(K1)+A1/5,B(K2)+A2/5,-1
11580 PLOT A1/5,B(K2)+A2/5,2
11590 CSIZE 3
11600 MOVE A1*.65,A9
11610 DRAW A1*.81,A9
11620 MOVE A1*.85,A9
11630 LORG 2
11640 LDIR 0
11650 LINE TYPE 1
11660 LABEL D$
11670 MOVE A1*1.2,A2*1.2
11680 K=0
11690 PAUSE
11700 GOTO 11690
11710 !
```

```
0 ! ********** KEY 24 (HARD COPY OF PLOT) **********
0 !
0 IF I=1 THEN 11780
0 BEEP
0 DISP "No hard copy can be made!  You must plot something first."
0 PAUSE
0 IF A7=1 THEN 11820
0 BEEP
0 DISP "No hard copy can be made!  Your plot was made on the plotter."
0 PAUSE
0 DUMP GRAPHICS
0 GCLEAR
0 PAUSE
0 GOTO 11840
0 !
0 ! ********** KEY 26 (PLOT ONLY) **********
0 !
0 IF I=1 THEN 11940
0 BEEP
0 DISP "You must make a plot with axes first!  Access key 10 before this key

0 PAUSE
0 GOTO 11920
0 IF K=1 THEN 11990
0 BEEP
0 DISP "You must make one or more changes through key 0,11,12,13,14 or 15 fi
"
0 PAUSE
0 GOTO 11970
0 S2=1
0 GOTO 9910
0 END
0 PLOTTER IS "GRAPHICS"
0 PLOTTER IS 7,5,"9872A"
0 PLOTTER 7,5 IS ON
0 X=0
0 FOR X1=1 TO 7
0 FOR X2=1 TO 3
0 LINE TYPE X1+3,2+2*X2
0 X=X+1
0 MOVE 0,2*X
0 DRAW 60,2*X
0 NEXT X2
0 NEXT X1
0 PAUSE
```

```
KEY 0
  -Clear
  CONT3260
  -Execute
KEY 1
  -Clear
  CONT5280
  -Execute
KEY 2
  Clear
  CONT5240
  -Execute
KEY 3
  -Clear
  CONT6850
  -Execute
KEY 4
  -Clear
  CONT8800
  -Execute
KEY 5
  -Clear
  CONT9330
  -Execute
KEY 6
  -Clear
  CONT9290
  -Execute
KEY 7
  -Clear line
  REWIND ":T15"
  -Execute
KEY 8
  -Clear
  CONT9400
  -Execute
KEY 9
  -Clear
  CONT9470
  -Execute
KEY 10
  -Clear
  CONT9540
  -Execute
KEY 11
  -Clear
  CONT8070
  -Execute
KEY 12
  -Clear
  CONT8100
  -Execute
KEY 13
  -Clear
  CONT8130
  -Execute
KEY 14
  -Clear
  CONT8160
  -Execute
KEY 15
  -Clear
  CONT8220
  -Execute
KEY 20
  -Clear
  CONT8930
  -Execute
KEY 24
  -Clear
  CONT11720
  -Execute
KEY 26
  -Clear
  CONT11870
  -Execute
```

scription of iables – 45 gram

A$	Volume unit description
A()	Base variable values
A	Total average annual investment
A1	Maximum value of production rate for plot
A2	Maximum value of yarding cost for plot
A3	Flag to indicate if plot is for base values, new values, or both
A4	Flag to indicate if yarding cost is to be plotted
A5	Line type identification number for plot
A6	Line type length for plot
A7	Flag to indicate if plot is on the screen or printer
A8	Flag to indicate if axes and plot or plot only is to be drawn
A9	Vertical distance to the plot and to the label of line type and identifier
B$	"YES" or "NO" response to visual prompts
B()	New variable values
B	Dummy to read DATA
C$	Identifier for base values
C()	Base variable values
D$	Identifier for new values
D()	New variable values
D	Total equipment depreciation
E$	Variable type description
E()	Percent change between base value and new value
E	Counter
F$	Temporary identifier for new values
F	Flag for determining if test for variable value equal to zero is required
G$()	Equipment identifier
H$	Heading
H	Flag to determine if part 1 of Print analysis routine has been accessed
H1	Flag to route program if part 2 of Print analysis routine is accessed prior to part 1
I	Flag to determine if key 10 has been pressed before key 26
J	Temporary storage for New Value
K	Flag to determine if key 26 can be accessed or not
K1	Value to allow plot of gross or net production rate
K2	Value to allow plot of gross or net yarding cost
K3	Flag to select plot labels
L	Line cost/hour
M	Number of base pieces of equipment
M1	Total repairs and maintenance cost
N	Number of the variable that is to be changed
N1	Number of the equipment piece
P	Flag to route to calculations for production rate and costs if VARIABLE CHANGES routine is accessed
P1	Printer mode (CRT or internal thermal printer)
Q	Direct labor cost plus supervision and overhead cost
R	Rigging cost/hour

S	Flag to indicate which part of Print analysis routine has been accessed
S2	Flag to indicate if key 26 (Plot only) is accessed
T	Tire or track cost/hour
U	Current number of base or new pieces of equipment (whichev is greater)
W	Percent change from base value to new value
W1	Percent change from base value to new value
X	Counter
X1	Counter
Z5	Flag to indicate if production rate is known (Z5=1) or unknown (Z5=0)
Z7()	Move in and move out cost (dollars/gross unit volume)
Z8()	Total setting change cost (dollars/gross unit volume)

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

General Technical Report PNW-109
July 1980

Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America

PLANNING FOREST ROADS TO PROTECT SALMONID HABITAT

CARLTON S. YEE and TERRY D. ROELOFS

USDA FOREST SERVICE
ANADROMOUS FISH HABITAT
PROGRAM

U.S. Department of Agriculture Forest Service
Pacific Northwest Forest and Range Experiment Station

ABSTRACT

The construction and existence of forest roads, landings, and decking areas may have significant effects on anadromous fish habitat. Major effects discussed in this paper are increased sedimentation from transportation networks, the hindrance to fish migration of drainage structures, and possible changes in water quality from road stabilization additives. Guidelines and recommendations to decrease or eliminate adverse effects are also given.

KEYWORDS: Fish habitat, water quality, sedimentation, road building (forest/logging).

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William R. Meehan, Technical Editor

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1980

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Preface

This is one of a series of publications summarizing knowledge about the influences of forest and rangeland management on anadromous fish habitat in Western North America. This paper addresses the effects on fish habitat of naturally occurring watershed disturbances and sets the scene for future discussions of the influences of human activities.

Our intent in presenting the information in these publications is to provide managers and users of the forest and rangelands of Western North America with the most complete information available for estimating the consequences of various management alternatives.

In this series, we will summarize published and unpublished reports and data as well as the observations of resource scientists and managers developed over years of experience in the West. These compilations will be valuable to resource managers in planning uses of forest and rangeland resources, and to scientists in planning future research. The extensive lists of references will serve as a bibliography on forest and rangeland resources and their uses for Western North America.

Previous publications in these series include:

1. "Habitat requirements of anadromous salmonids," by D. W. Reiser and T. C. Bjornn.

2. "Impacts of natural events," by Douglas N. Swanston.

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INTRODUCTION

A forest transportation system can have significant effects on anadromous fish and their habitats. Often, the effects have been adverse. Examples of adverse changes caused by forest roads, log sorting, and log-storage areas include increased sediment and organic debris in streams, changes in water quality and quantity, formation of physical barriers to the movement of adult and juvenile fish, and increased human access to previously remote or isolated areas.

This report describes how elements of a forest transportation system cause environmental changes that ffect anadromous fish habitat nd provides guidelines for the esign, construction, and aintenance of these facilities o minimize adverse effects. n the first publication in his series, Reiser and Bjornn ave discussed habitat equirements of anadromous almonids; we will limit our iscussion to effects on the ish and their habitats that irectly stem from forest roads, og sorting, and log-storage reas.

SEDIMENTATION

The fact that forest roads cause increased erosion and sedimentation cannot be disputed. Increased sediment in streams after construction of roads can be dramatic and long-lasting. The incremental sediment contribution per unit area from roads is often many times that from all other land-management activities, including log skidding and yarding. Based on total area, however, both roads and logging appear to contribute eroded material nearly equally. Gibbons and Salo (1973) reviewed over 25 articles on the impact of timber harvesting on stream environments and concluded that forest roads are the primary initiator of erosion caused by human activities.

The primary mechanisms by which sediment from roads reaches streams are mass soil movement and surface erosion. Because forests and steep terrain seem, for the most part, to go together, mass-movement erosion is the predominant mode of sediment transport from forest roads. Swanston and Swanson (1976) described four main types of mass movements common to Western forest lands. Soil creep, slump-earthflows, debris avalanches, and debris torrents are differentiated mainly by speed of travel and shape of the failure surface. The construction of roads across some slopes can initiate or accelerate slope failure--from several to hundreds of times, depending on such variables as soil type, slope steepness, presence of subsurface water, and road location (Anderson 1971, Larse 1971, Swanston 1971, Swanson 1975, Swanston and Swanson 1976).

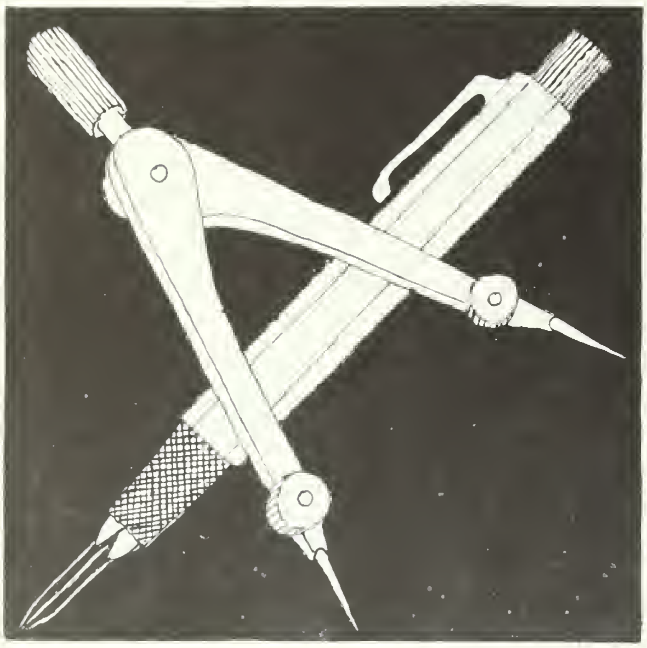
The construction of a road, landing, or log-sorting area on a hillslope is a severe and concentrated disturbance. Such construction can initiate mass movements of soil by overloading the slope from improper fill construction, undercutting an already marginally stable slope, and impeding or changing surface and subsurface runoff regimes (Larse 1971, Burroughs et al. 1976). Table 1 shows how severely roads can increase erosion rates as indicated by the rate of debris-avalanche erosion in four widely separate watersheds in Western Canada and the United States (Swanston and Swanson 1976). The values shown are only for debris avalanches and do not include amounts from other road-associated mass or surface events.

able 1--Debris-avalanche erosion in forest, clearcut, and roaded areas (Swanston and Swanson 1976).

Site	Period of record	Area		Slides	Debris-avalanche erosion	Rate of debris-avalanche erosion relative to forested areas
	Year	Percent	Km^2	Number	$M^3/km^2 \cdot yr$	
tequaleho Creek, Olympic Peninsula (Fiksdal 1974)						
orest	84	79	19.3	25	71.8	X 1.0
learcut	6	18	4.4	0	0	0
oad right-of-way	6	3	0.7	83	11 825	X 165
			24.4	108	71.8	
lder Creek, western Cascade Range, Oregon (Morrison 1975)						
orest	25	70.5	12.3	7	45.3	X 1.0
learcut	15	26.0	4.5	18	117.1	X 2.6
oad right-of-way	15	3.5	0.6	75	15 565	X 344
			17.4	100		
elected Drainages, Coast Mountains, S.W. British Columbia (O'Loughlin 1972, and personal communication)						
orest	32	88.9	246.1	29	11.2	X 1.0
learcut	32	9.5	26.4	18	24.5	X 2.2
oad right-of-way	32	1.5	4.2	11	282.5[1]	X 25.2
. J. Andrews Experimental Forest, western Cascade Range, Oregon (Swanson and Dyrness 1975)						
orest	25	77.5	49.8	31	35.9	X 1.0
learcut	25	19.3	12.4	30	132.2	X 3.7
oad right-of-way	25	3.2	2.0	69	1 772	X 49

1/ Calculated from O'Loughlin (1972, and personal communication), assuming that the area in road construction in and outside clearcuttings is 16 percent of the area clearcut.

In addition to sediment originating from mass erosion associated with roads, erosion from road surfaces also contributes sediment to streams. Surface erosion from fill and cut slopes, road surfaces, and drainage ditches can severely affect streams below the right-of-way (Burns 1970, Brown and Krygier 1971, Larse 1971, Gibbons and Salo 1973, Farrington and Savina 1977). Although this type of erosion is difficult to measure, investigations in specific soil types and climatic conditions have given some idea of the soil loss from forest roads (Fredriksen 1965, Megahan and Kidd 1972). For example, Haupt (1959) found that road-fill slopes were the primary source of sediment moving downslope. Packer and Haupt (1966) assessed losses by surface erosion from forest roads in the northern Rocky Mountains and presented guidelines to reduce surface erosion and sedimentation.



CONTROLLING SEDIMENTATION THROUGH PLANNING AND DESIGN

Larse (1971) pointed out that the most important steps to minimize the impact of road construction on streams usually occur during reconnaissance, planning, and route selection, rather than during or after construction. He and others have also repeatedly pointed out that problems can be reduced by including specialists such as geologists, soil scientists, fisheries biologists, and hydrologists on the planning team. Key environmental problems and constraints are too often overlooked when routes are located and roads designed by one person. Numerous guides for reducing and controlling erosion from roads have been devised (Trimble and Sartz 1957, Haupt 1959, Packer and Haupt 1966, Gonsier and Gardner 1971, Larse 1971, Burroughs et al. 1976, Megahan 1977). Larse (1971)[1/] summarized guidelines for route selection to minimize erosion as follows:

- Plan roads to take maximum advantage of natural log landing areas.
- Take advantage of benches, ridge tops, and the flatter transitional slopes near the ridges and valley bottoms. Avoid midslope locations on steep, unstable slopes. Grades of 14-16 percent are practical for low-use roads.
- Locate valley-bottom roads to provide a buffer strip of natural vegetation between road and stream. Position roads on the transition between the toe slope and terrace to protect the road slopes from flood erosion. Roads should not be built in valley bottoms if encroachment on the stream will result.
- Locate ridge-top roads to avoid headwalls at the source of tributary drainages.
- Vary road grades, when possible, to reduce road-surface erosion and flows from culverts and drainage ditches.
- Select stream crossings carefully to take advantage of the best drainage.

1/ For more detailed recommendations refer to Larse (1971).

In addition, where stream protection for fisheries is important, the recommendation by Farrington and Savina (1977) that no roads be built in a stream's inner gorge should probably be added to the above six recommendations. Farrington and Savina's recommendation may be considered merely an extension of Larse's third guideline, however.

After the route is selected, positive measures to reduce erosion should be incorporated into the road design and construction. The following recommendations by Larse (1971, see footnote 1) summarize good erosion-control measures that should be built into forest roads:

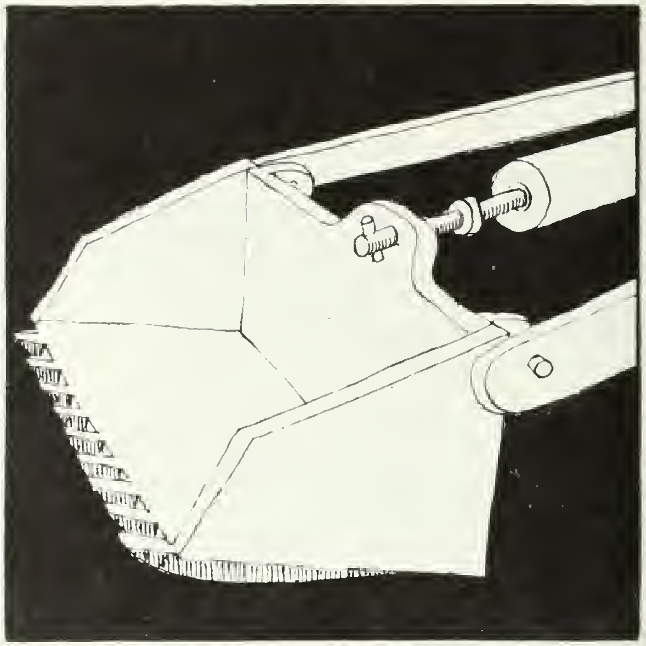
- Within limitations necessary for type and volume of traffic, fit roads to terrain with minimum of road width.
- Minimize excavation with a balanced earthwork design whenever possible. Bench or terrace and drain natural slopes to provide a sound foundation for embankments.
- Design rolling grades to reduce surface water velocity and culvert requirements, but avoid coinciding horizontal and vertical curves that concentrate surface runoff.
- Design cut and fill slopes as steep as possible consistent with the stability and strength of soil and rock formations. Round tops of cut slopes to reduce sloughing and surface ravel.
- Use retaining walls, with properly designed drainage, to reduce excavation, contain bank material, and prevent stream encroachment.
- Vary ditch and culvert requirements depending on topography, road gradient, soil erodability, and expected intensity of rainfall.
- Place culverts to avoid discharge onto erodible slopes or into streams. Install cross-drainage culverts immediately upgrade of headwalls and stream crossings to prevent ditch sediment from entering the stream.
- Design drainage structures to accommodate the flow of streams based on at least a 25-year flood frequency (50 years for large permanent bridges and major culverts), with due consideration given to the possibility of bedload and debris restricting flow capacity of the structure.
- Determine the extent and type of fish habitat before selecting criteria for structure design. Bridges and arch culverts are preferred in streams with migratory fish. Where culverts are used, gradient should be less than 1 percent, and a constant minimum flow of 5-6 inches should be provided at maximum velocities of 6-8 ft/s during low-water stages. Scouring at the outlet can be eliminated by energy dissipators, such as heavy rock riprap, weirs, or gabions.

- Avoid channel changes and protect embankment with riprap, masonry headwalls, or other retaining structures. Align large culverts with the natural course and gradient of the stream. Design the placement of large culvert inverts lower than the natural streambed. Floatable debris during high streamflow can plug small culverts and restrict flow at larger culverts and bridges, causing severe road embankment, streambank erosion, or channel changes. Trash racks, if properly designed, constructed, and maintained, can reduce culvert plugging. Trash racks can sometimes be barriers to fish movement; other measures to insure culvert or bridge survival should be considered.

- Most forest roads should be surfaced. The type of surface will usually be determined by traffic, maintenance objectives, desired service life, and the stability and strength of the road foundation material.

- Provide for vegetative or artificial stabilization of cut and fill slopes in the design process.

- Prior to completion of design drawings, field check the design to assure that it fits the terrain, drainage needs have been satisfied, and all critical slope conditions have been identified and adequate design solutions applied.



ROAD CONSTRUCTION AND MAINTENANCE

A challenge to the roadbuilder is to construct the designed facility with a minimum of disturbance, without damage to or contamination of the adjacent landscape, water quality, and other resource values. Some of the most severe soil erosion can be traced to poor construction practices, insufficient attention to drainage during construction, and operations during adverse weather conditions.

Construction operations can be conducted in most terrain and climatic conditions if the roadbuilder takes precautions to minimize soil erosion and stream sedimentation. Good technical engineering work will not itself control erosion during construction, but work must be deliberately planned, scheduled, and controlled so that different phases are performed under optimum conditions. When soil moisture is excessive, earthwork

operations should be suspended and measures taken to weatherproof the partially completed work. Work within or adjacent to streams and water channels should not be attempted during periods of high streamflow, intense rainfall, or migratory-fish spawning.

The clearing of debris underlying, supporting, or mixed with embankment or waste material is a common cause of road failure and mass soil movement. The necessary slope bonding, shear resistance, and embankment density for maximum stability cannot be achieved unless organic debris is disposed of before embankment construction is started. Woody debris must also be removed from all drainage channels and headlands above or at the source of drainage courses.

Although many techniques are commonly practiced to minimize erosion during construction, the most meaningful are related to how well the work is planned, scheduled, and controlled by the roadbuilder and those responsible for determining that work satisfies design requirements and land-management objectives.

Planned regular maintenance is necessary to keep roads in good condition, but maintenance is too often neglected or improperly performed, resulting in deterioration. The vast network of existing forest roads, many of which have only light or intermittent use, present real problems as fuel and other maintenance costs increase.

To build and use a road requiring no maintenance is neither practical nor economical. Maintenance requirements and expense related to traffic use can and should be considered in planning and design to insure that the completed road can be maintained most economically. Where soil erosion and sedimentation are of concern to the forest manager, the additional expense of constructing a road with proper attention to its stability and proper drainage can generally be amortized in a few years by lower cost of upkeep.

Suggested maintenance practices to prevent or control erosion and stream sedimentation are presented by Larse (1971, see footnote 1):

- Blading and shaping should be performed to conserve existing surface material.
- Road inlet and outlet ditches, catchbasins, and culverts should be kept free of obstructions.
- Slide material should be removed promptly when it obstructs drainage systems.
- Herbicides should not be used where they might contaminate water courses.

ROAD STABILIZATION ADDITIVES

The use of various chemicals to improve bearing capacity and quality of running surface of forest roads has had a varied history in the Western United States. Probably the most common additive applied on forest roads is some type of oil to minimize dust. Freestone (1972) estimated that 200 million gallons a year of waste crankcase oil were added to rural roads in the United States. The amount of other waste and nonwaste oils applied to rural roads in the United States, including forest roads in the West, is unknown.

In addition to oils, other chemical compounds used to improve forest road quality include sodium chloride, calcium cloride, hydrated lime, and waste pulpmill liquors. Commercial formulations especially designed for road stabilization also are being used more commonly on forest roads. Unfortunately, we know even less about the use of chemical stabilizers on forest roads than we do about road oil.

Most of the published information on road stabilization with chemicals is for the Eastern United States and Canada (Duncan 1965, Gayer 1965, Paterson et al. 1970), and we have never found the question of water-quality impacts addressed.

Because of the increasing cost and decreasing availability of high-quality surfacing rock, the use of various road-stabilizing additives on Western forest roads can only increase. With increased use, surface and subsurface runoff from oiled and chemically treated roadways could certainly cause localized water-quality problems that could affect fish and their habitat. Little research has been done that can allow us to guess at the consequences of increased road-additive use.

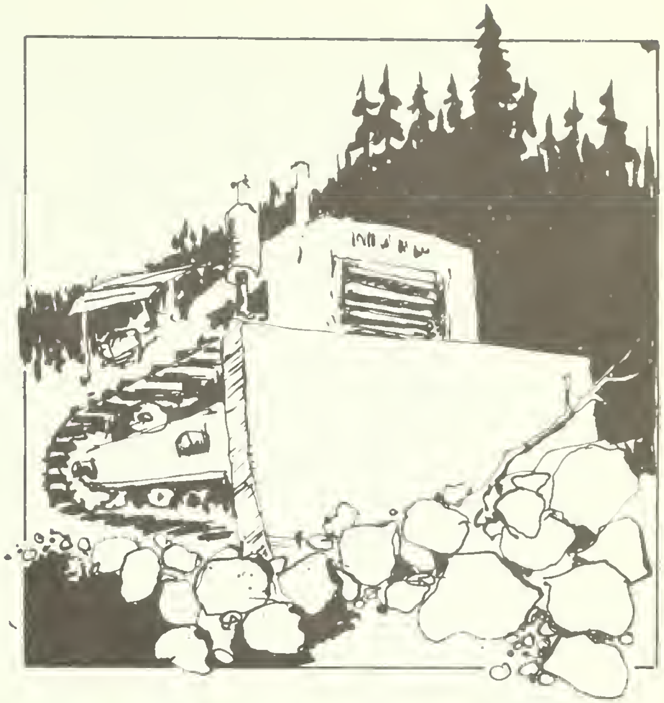
Burger (1973) studied the acute toxicity and long-term effects of Chevron PS-300[2/] road oil, a commonly used dust-control agent, on juvenile coho salmon (Oncorhynchus kisutch (Walbaum)). The 96-hour TL_{50} for fish weighing 274/lb and 22/lb were 1350 and 1500 parts per million, respectively. Long-term (30-53 days) effects of exposure to road oil included reduced growth rates, increased susceptibility to disease, and histological abnormalities of liver and spleen tissue.

2/ The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

A study of runoff from rural roads by Freestone (1972) indicated that 99 percent of road oils left the roadway. How much was lost by volatilization, adhesion to vehicles, dust transport, biodegradation, or by rain runoff, however, could not be determined. The effect of heavy metals in the road oils may be more important than the effect of the oil itself. Clearly the location of the road relative to waterways, method of application, occurrence of rain after application, and other factors are important in evaluating the possibility of significant contamination of fish habitat.

Our search of the literature produced nothing on the effects of road-stabilization chemicals on fish or their habitat. A fairly extensive literature is available on the effects of sodium chloride and calcium chloride on water quality, but only in their use as deicing agents (Struzeski 1971). Deicing salts are applied at 10 to 20 times the rate used for road stabilization. The method and season of application are also different for the two purposes; the deicing literature is therefore of little value for inferring water-quality impacts from increased use of this chemical for road stabilization in western forests.

Little is known about the consequences of increased use of road oil and stabilizing chemicals, and we are not even sure there are deleterious effects to anadromous fish or their habitat under current application practices. The likelihood of increased use of road-stabilizing additives in western forests, however, indicates that the effects on water quality deserve future research.



ROADS AND FISH MIGRATION

Salmon (Oncorhynchus spp.), steelhead (Salmo gairdneri Richardson), and other anadromous fish require unobstructed access to upstream spawning areas. Road culverts can be barriers to migration, usually because of outfall barriers, excessive water velocity in the culvert, insufficient water in the culvert, lack of resting pools below culverts, or a combination of these conditions (fig. 1).

The incorporation of fish passage facilities must be based on an assessment of habitat quality and access. Natural barriers downstream or immediately upstream from the site may preclude the need for fish passage facilities. In one National Forest, standard policy is to provide fish passage when 1/4 mile or more of good-to-excellent fish habitat exists above the pipe. Usually, a knowledgeable fisheries biologist must be consulted to assess the habitat.

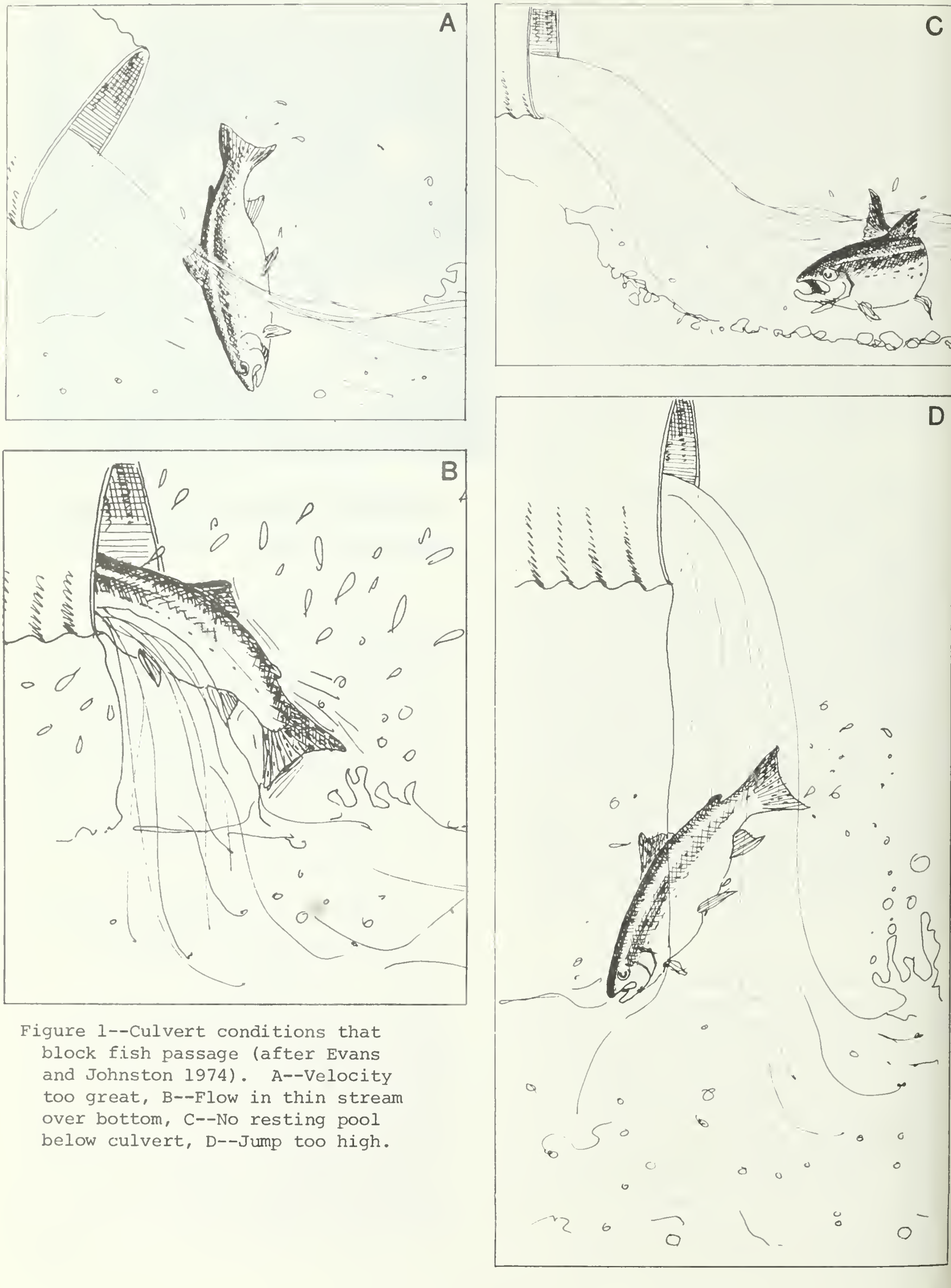


Figure 1--Culvert conditions that block fish passage (after Evans and Johnston 1974). A--Velocity too great, B--Flow in thin stream over bottom, C--No resting pool below culvert, D--Jump too high.

Because bridges usually cause less disturbance to streams than culverts, they are often preferred for assuring fish passage. Where concrete foundations and piers are constructed, however, bridges have created problems, such as scour and lowering of streambeds. Construction of anti-scour weirs, sills, and aprons may be required to prevent changes in the streambed.

Log bridges should not cause serious problems for fish passage if properly constructed and maintained. Where log bridges have caused problems, it is usually because there is insuffcient stream channel clearance to accommodate high flows. Bridge and earth abutments then either wash out, causing damage to the stream below, or remain in place, catching debris and forming a debris barrier to migration.

Unfortunately, building bridges on low-volume forest roads often proves to be uneconomical or impractical, and culverts become necessary. Forethought can greatly reduce or eliminate the barrier effects a particular culvert can have; sometimes culverts must be substantially redesigned. Most obstructions, however, can be easily prevented if the potential is recognized during planning.

If culverts are deemed necessary for crossing a stream, the road designer should be aware of several factors that affect the fish and also of the choices of drainage structure and location. The first question is whether or not the stream above the proposed culvert is used by anadromous fish. If not, the culvert design problem is reduced to the typical one of adequate discharge capacity. If the answer is yes, however, then the designer must know which species are in the stream, their life history, and the season or seasons of migration. For fish to overcome obstacles in their migration, the following conditions are necessary:

- A resting pool should be present immediately below the obstacle. This allows the fish to conserve energy and obtain a good start at overcoming the obstacle.

- Individual jumps should not be too high. The lower the jump, under water conditions that occur when migration takes place, the less difficulty the fish will have in passing over the obstacle. In general, a single vertical jump of 1 foot can be negotiated by resident adult trout. If a series of jumps is required, however, a half foot at each is preferable. Salmon and steelhead can normally negotiate single jumps of 2-3 feet without difficulty. In a series, however, individual jumps should not be over a foot high.

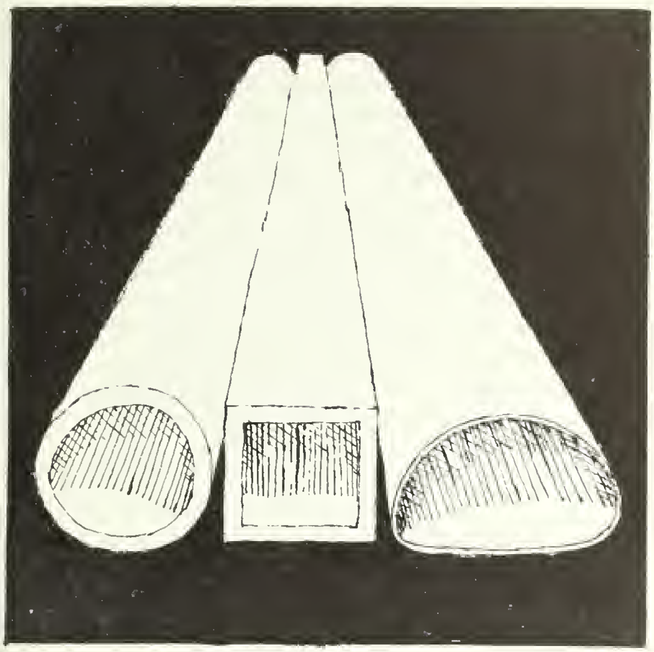
- In general, 6 inches is minimum water depth for resident trout; 1 foot is required for salmon and steelhead. Maximum allowable velocities should be around 4 feet per second (ft/s) for trout and 6 ft/s for salmon and steelhead. These maximum velocities vary with distance and fish species.[3/]

- If swimming distance is over 50-100 feet in a difficult passage, resting pools may be required enroute. This applies to culverts and bridge aprons in particular. The need is determined by examining the average swimming ability of the least capable species using the stream relative to water velocities and distance for passage through the structure.

- Fish are often near exhaustion after passing over or through a difficult obstacle and require a resting area upstream. If one is not available, the fish are often swept downstream over the obstacle and must again exert the energy to surmount it.

- Three hydraulic criteria are important. The most desirable culvert installation is one that causes no sudden increase in water velocity above, below, or through the culvert. Culverts are best located where the stream reach is of similar alignment above and below the culvert for several hundred feet. And, the culvert gradient should be as near zero as possible. When these three conditions are not met, problems in fish passage may occur.

[3/] Unpublished report, "Fisheries handbook of engineering requirements and biological criteria. Useful factors in life history of most common species," by M. C. Bell. Submitted to Fish.-Eng. Res. Program, Corps of Eng., North Pac. Div., Portland, Oreg. 1973.

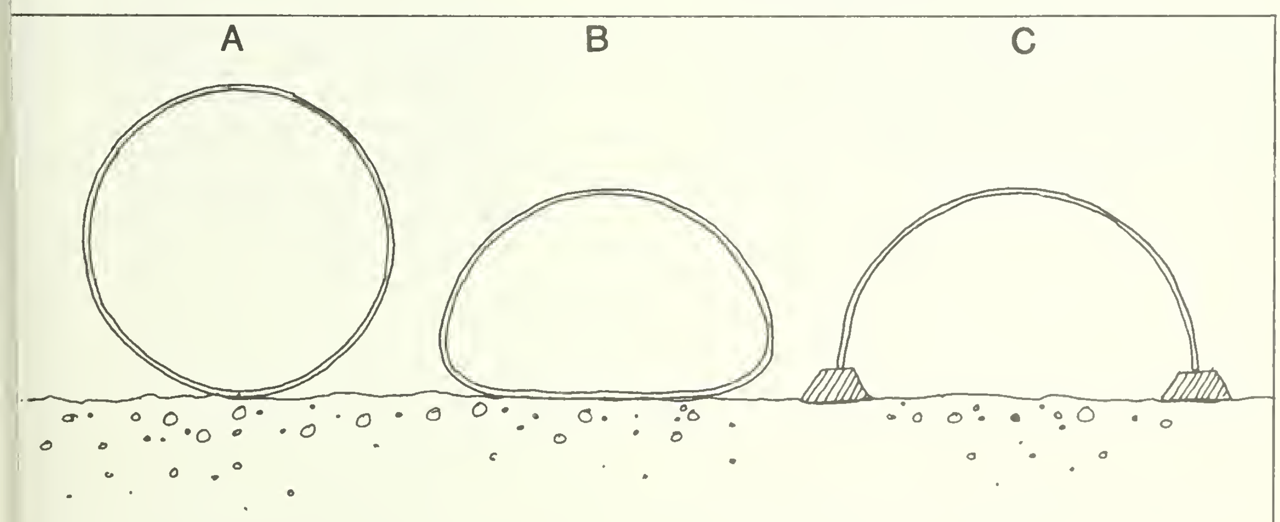


Metal culverts, classified by shape, are standard corrugated round, standard corrugated pipe-arch, and structural plate-arch (fig. 2). The first two may be prefabricated, as is usual for the smaller sizes (up to 60 inches diameter and 72-x-44-inch span by rise), or may be of multiplate design. Type three culverts are always of multiplate design because they are so large and usually fabricated on site.

TYPES OF CULVERTS

Three types of metal culverts are commonly used on western forest roads. (Cylindrical concrete culverts generate extremely high water velocities because they are smooth inside. Internal velocities may be many times those in corrugated metal culverts of the same diameter and gradient. Concrete culverts are thus not suitable for fish passage.)

Figure 2--Typical cross sections of the most commonly used metal culverts on forest roads. A--Corrugated round metal culvert, B--Corrugated pipe-arch metal culvert, C--Structural plate-arch with concrete footings (also available in semicircular cross section).



The structural steel arch set in concrete footings (fig. 2c) is the most desirable culvert type for fish because the natural stream is left undisturbed. Little contracting in width occurs at either end of the culvert, and no signficant changes in velocity. Where concrete footings are not practical, split wide-flanged buried steel footings have been used recently in place of concrete footings. Disadvantages of this installation are mainly increased cost of installation and the high fill needed. Many fisheries biologists believe that the arch type is the only acceptable culvert where fish passage is required (Evans and Johnston 1974).

Pipe-arch culverts (fig. 2b) are less desirable than the structural steel arch, but they can usually be installed to allow fish passage. Fabricated in smaller sizes, they can be used in smaller, lower fills where structural steel arches would not fit. Where pipe arches are used, the gradient must be kept below 1 percent to minimize water velocities. During periods of low flow, the water in culverts with this shape may be spread so thin across the bottom that fish passage is impossible. Baffles may then be needed to increase the flow depth through the pipe-arch (baffle systems are discussed in more detail later).

Although the standard corrugated round culvert (fig. 2a) is the type most commonly used on western forest roads, it is the least desirable for fish passage. Because the width constriction from stream channel to culvert is usually severe, the gradient of the tube must be at or near zero percent to minimize water velocities through the pipe. This type of culvert is also most likely to be installed with its outfall above the tailwater elevation, producing an outfall barrier (fig. 1). Elevated outfalls of this type are to be avoided or mitigated by some means.

Thousands of streams have had culvert crossing with little or no thought to the effects on fish populations. One poorly installed culvert can affect the fish population of an entire small stream drainage. Poor culvert design and location can still be ranked among the most devastating problems for fish habitat in western forests.

Some general considerations for culvert installation are:

- Avoid installation of round culverts where fish passage might be difficult. Install either open-arch culverts or bridges, especially if culverts longer than 100 feet are required or where the stream gradient is steep (>2 percent).

- A single large culvert is better than several small ones, because it is less likely to become plugged and carries water at much lower velocity.

- Diameter of culverts must be adequate to pass maximum flows. Washing out of culverts and their earth fills, besides damaging the road, is also a source of sedimentation.

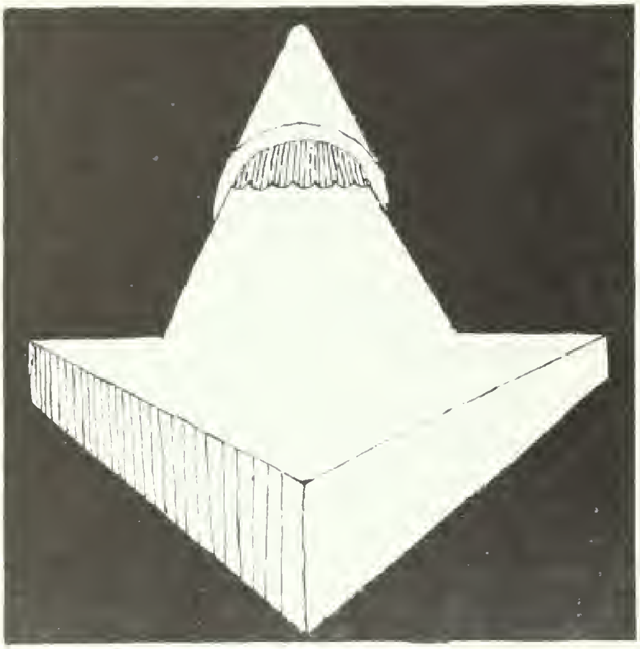
- Place the entire culvert length slightly below normal stream grade to reduce fish passage problems and prevent a lowered streambed. Strive for an installation gradient at or near zero percent; otherwise, avoid round culverts.

- The two most important considerations for fish in culverts are the maximum acceptable water velocity and the minimum acceptable water depth for the species.

- Because streams used by salmonids often fluctuate widely with occasional high peak flows, an acceptable practice on construction projects has been not to require flow conditions suitable for fish passage during the 5 percent of the year when flow peaks are highest (Evans and Johnston 1974). These flood peaks are unusually high and normally short. Fish normally do not migrate during peak flows, so little disruption of fish migration occurs. The practice often results in substantial savings in construction costs for fish passage. The aim, therefore, should be to insure fish passage during 95 percent of a year, or 90 percent of the time on a 6-month basis. Any structure for fish passage must function through a sufficiently wide range of flows to accommodate the period of migration.

- Avoid baffling of culverts if possible or use a larger culvert, a reduced gradient, or both. Baffles normally require additional maintenance and occasionally cause debris accumulations. Baffles are sometimes necessary with high water velocities or in correcting fish passage problems at existing culverts.

- Where culverts are installed in stream sections with steep gradients, improve resting pools, cover, and bank projection along the stream for several hundred feet above and below the culvert. Maintaining a stable stream bottom through the culvert-influenced area is essential.



WATER VELOCITY IN CULVERTS

Swimming ability of salmonids increases with size of the fish. Hence what species uses the culvert has a bearing on the allowable maximum velocity. Specific velocity limits for any anadromous species cannot now be cited with authority, but some general guidelines are available for adult fish. Metzker (1970) reported that for trout up to 15 inches, eight ft/s should be considered maximum for short distances. Adult salmon can travel through and sustain velocities of 12 ft/s for short distances. Metzker also pointed out that the culvert velocity a fish can overcome varies not only with the fish's size, but also with the distance between resting pools below and above the culvert. The Oregon State Game Commission (1971) recommended maximum water velocities of 8 ft/s for adult salmon and steelhead and 4 ft/s for trout. The recommended velocities in Oregon, however, are for round culverts up to 100 feet (30.5 m) in length. Water velocities in longer culverts should not exceed 6 ft/s for adult salmon and steelhead and 3 ft/s for trout.

To aid road designers in estimating the water velocities through culverts, both the Oregon State Game Commission (1971) and the USDA Forest Service (Evans and Johnston 1974) have produced series of culvert velocity curves based on Manning's equation (Chow 1959). The Oregon State Game Commission curves are for round metal culverts only, ranging in diameter from 24 to 84 inches. Gradients range from 0.25 to 5.0 percent. Figure 3 is an example of the Oregon velocity curves for a 72-inch culvert. Because fish passage through culverts normally occurs between a minimum depth of 3 inches and a maximum depth of two-thirds the pipe diameter, the Oregon curves cover only these depths.

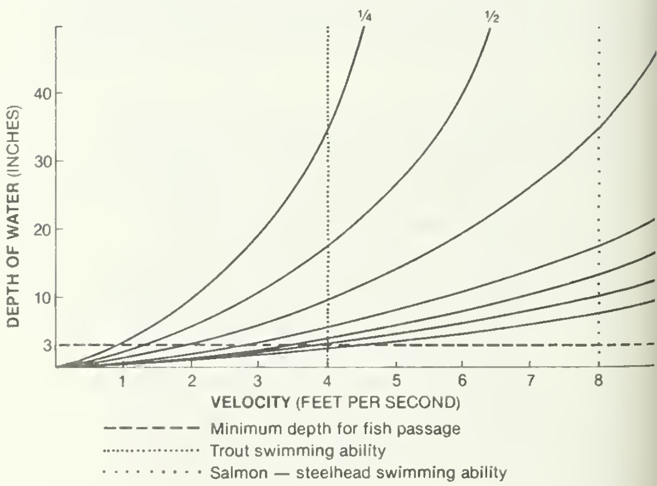


Figure 3--Velocity curves for a 72-inch diameter round culvert (after Oregon State Game Commission 1971).

The USDA Forest Service velocity curves are more detailed than the ones for Oregon; curves have been provided not only for round culverts (36- to 120-inch), but also for concrete box culverts (26- to 120-inch) and for 3-x-1, corrugated metal pipe-arches (7 ft x 5 ft 1 inch to 16 ft 7 inch x 10 ft 1 inch, span by rise). Also the USDA Forest Service curves yield both velocity and depth of flow for any given discharge, culvert gradient, and diameter. Figure 4 illustrates the format of the USDA Forest Service curves for a metal pipe-arch.

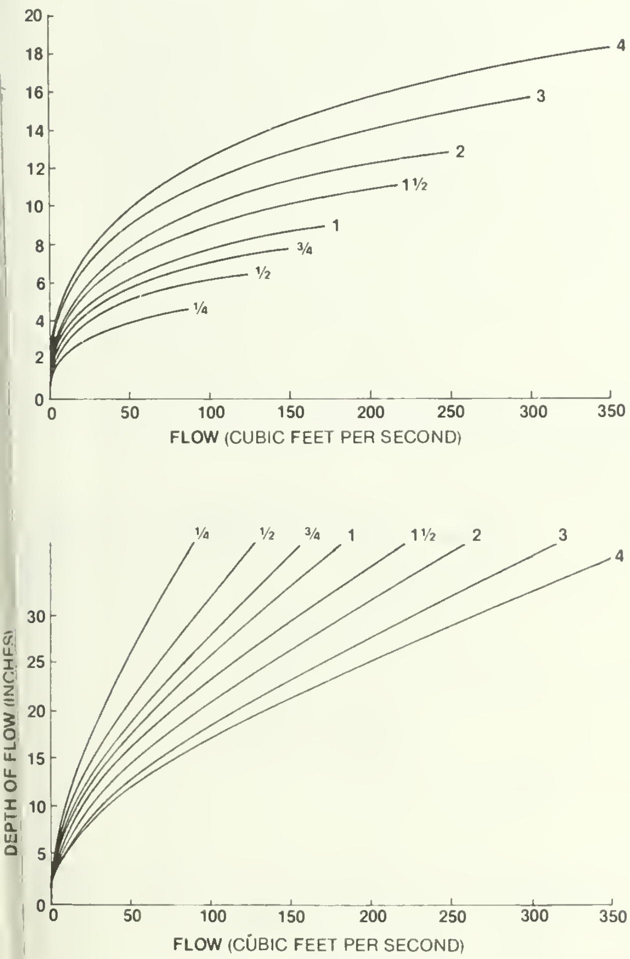


Figure 4--Velocity and depth-of-flow curves for a 7-foot by 5-foot 1-inch pipe-arch (after Evans and Johnston 1974).

Salmonid spawning streams in the West are often mountain streams with steep gradients. Even culverts placed on the same grade as the original streambed may exhibit water velocities greater than migrating fish can overcome; to control water velocities in culverts then, installing baffles may be necessary.

Constructing a fish passage facility through a culvert essentially opposes the reason for the culvert, which is to discharge water downstream at the highest possible rate with the smallest culvert possible. On the other hand, the structure for fish passage attempts to produce pockets of low velocity in the culvert where fish can rest momentarily. To provide these low velocities, energy dissipators of some form are required--normally, baffles or small water barriers.

Baffle designs are probably as numerous as the people installing them. Little information is currently available on the hydraulic principles of various types of baffles. Additional applied research in this field should be encouraged. The best information on baffle design is in a Washington Department of Fisheries report (McKinley and Webb 1956); the principles are sufficiently sound to be used as present guidelines, pending results of further research.

Certain general principles have been developed through long experience with baffles in culverts:

- Avoid using baffles whenever possible. Solve your fish-passage problems preferably through considerations of bridges, arch culverts or round culverts of sufficient size, and installations of low water velocity at or below streambed level.

- If higher velocities, extensive distance, or both are unavoidable in a round or box culvert installation, baffles will be necessary. Baffles and resultant quieter waters allow a fish to swim in short spurts straight through high velocities and enter a rest area parallel to the higher velocity flow.

- A large single culvert provides better fish passage than several smaller ones. Where multiple units are required, only one must be baffled to pass fish. Select the culvert for baffling based on the route most likely to attract fish. At such installations, provisions should be made for diverting low flows through the baffled culvert only.

- The baffle design illustrated in figure 5 is recommended for general use by the California Region of the U.S. Forest Service (Evans and Johnston 1974). For the design in figure 5 to be readily adaptable to installations of various sizes, the dimensions have been given as percentages of total width of the baffled section. These

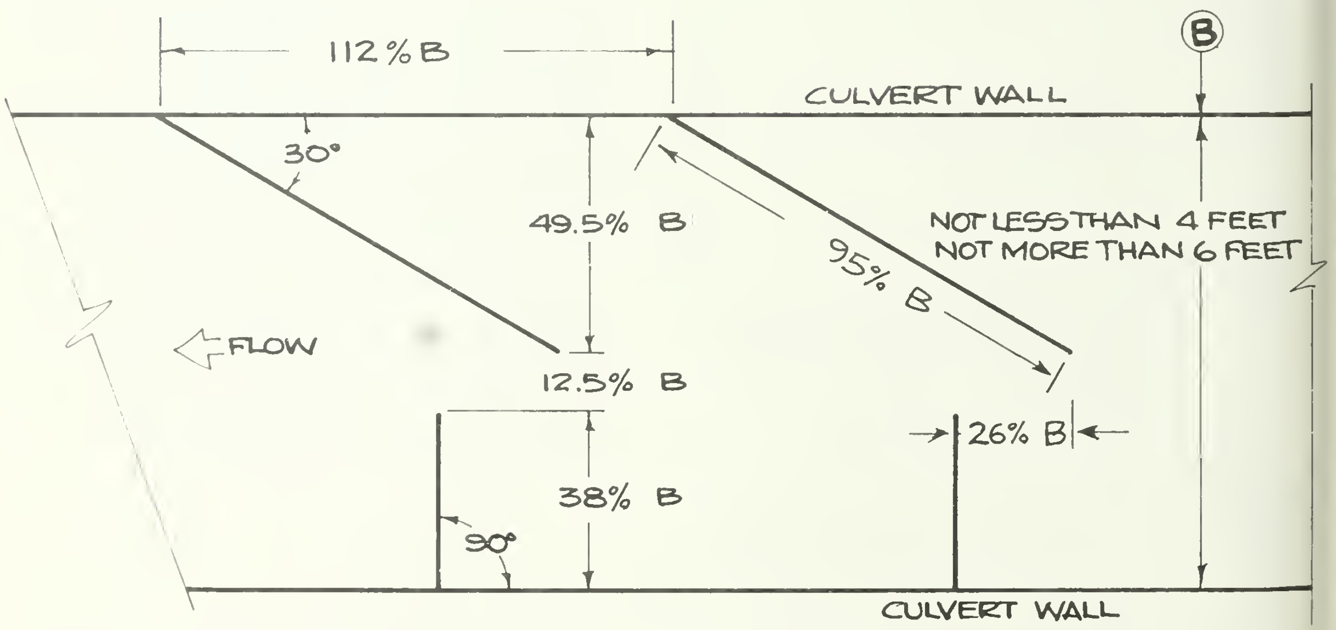


Figure 5--Baffle-pattern arrangement for metal culverts (after Evans and Johnston 1974). B equals clear width of box culvert, intercept width is 1 foot above invert (round or arch culverts), and all baffles are 1 foot high.

dimensions and angles of baffles have been determined through research and should be adhered to. Baffles should be a minimum of 1 foot high and 5-6 inches wide.

- Calculate the relative efficiency of the culvert with and without baffles, because the passage of water through the culvert will be impaired by the baffle structures. Because a large safety factor is required, most culverts are overdesigned for the discharge conditions, and the actual impairment of the culvert's ability to discharge is relatively small. The ultimate culvert size required is, of course, a decision for the engineer.

- Construction materials for baffles may be wood, metal, or concrete, depending upon the local situation. Wood is sometimes preferable because it offers greater resilience when hit by moving objects and also can be replaced more easily. Concrete baffles may be pre-cast and drilled or grouted into place. Metal baffles are normally bolted onto the culvert floor, using metal plates for added strength.

- "Most baffles are designed to operate best when water flow is just overtopping them and their effectiveness is inversely proportional to the depth of water over them." (Gebhards and Fisher 1972).

- Placing baffles properly in a new culvert before its installation is far less expensive than trying to alter an installed culvert.

- For round metal culverts, a minimum culvert diameter of 5 feet is required to provide a 4-foot-wide space for baffle installation (fig. 5).

- Baffles may have value other than controlling velocity; for example, they increase water depth in the pipe to provide fish passage during low flow periods. Another example would be to convert a culvert with a steep gradient into a series of pools--in effect, creating a modified fish-ladder.

CULVERT OUTFALL BARRIERS

Culverts can be insurmountable barriers to migrating fish when the outlet of the culvert is so far above the tailwater that fish cannot enter the pipe; this condition is termed an outfall barrier (fig. 1).

Where new culverts are to be installed on streams with migrating fish, every attempt should be made to avoid constructing an outfall barrier. Putting a new culvert outlet below the tailwater elevation is sometimes not possible, or--more commonly--an existing culvert forms an outfall barrier.

One way to correct a culvert outfall barrier is to provide for one or a series of low-head dams below the culvert outfall (fig. 6). These dams may be nothing more than hand-placed rock "reefs" or wire-basket gabions filled with local rock, or concrete sills. These downstream dams raise the tailwater elevation and flood the culvert. Access by fish is not only enhanced, but water velocity in the culvert is decreased. The downstream dams should not create outfall barriers themselves and should therefore be limited to about 1 foot in height or, for dams of greater heights, have a pass-through notch in the center. Because the backflooding decreases velocity and hence discharge, a culvert of larger diameter may be necessary to handle peak flows. Also, armouring the downstream side of the low-head dams may be necessary to prevent scouring from the cataracts formed.

In some streams, the range of flows is so wide that it is impossible not to have the culvert outlet above tailwater at some time. Also, where severe fluctations in flow require large culverts, problems are sometimes encountered in providing fish passage during low flows because of the shallow flow over the broad culvert bottom. Then, stacked- or multiple-culvert installations can be used to provide fish passage (fig. 7). Placing the stacked culverts at different elevations assures adequate discharge capacity as well as fish passage over a wider range of flows. The lower, smaller culvert would concentrate low flows and assure fish passage then. Note our previous statements on the inhibitory effects full culverts have on fish passage.

Figure 6--Gabion or concrete sills can raise tailwater elevation to facilitate fish entry into the culvert; this weir construction was used to improve fish passage at the mouth of Gold Creek (after Evans and Johnston 1974).

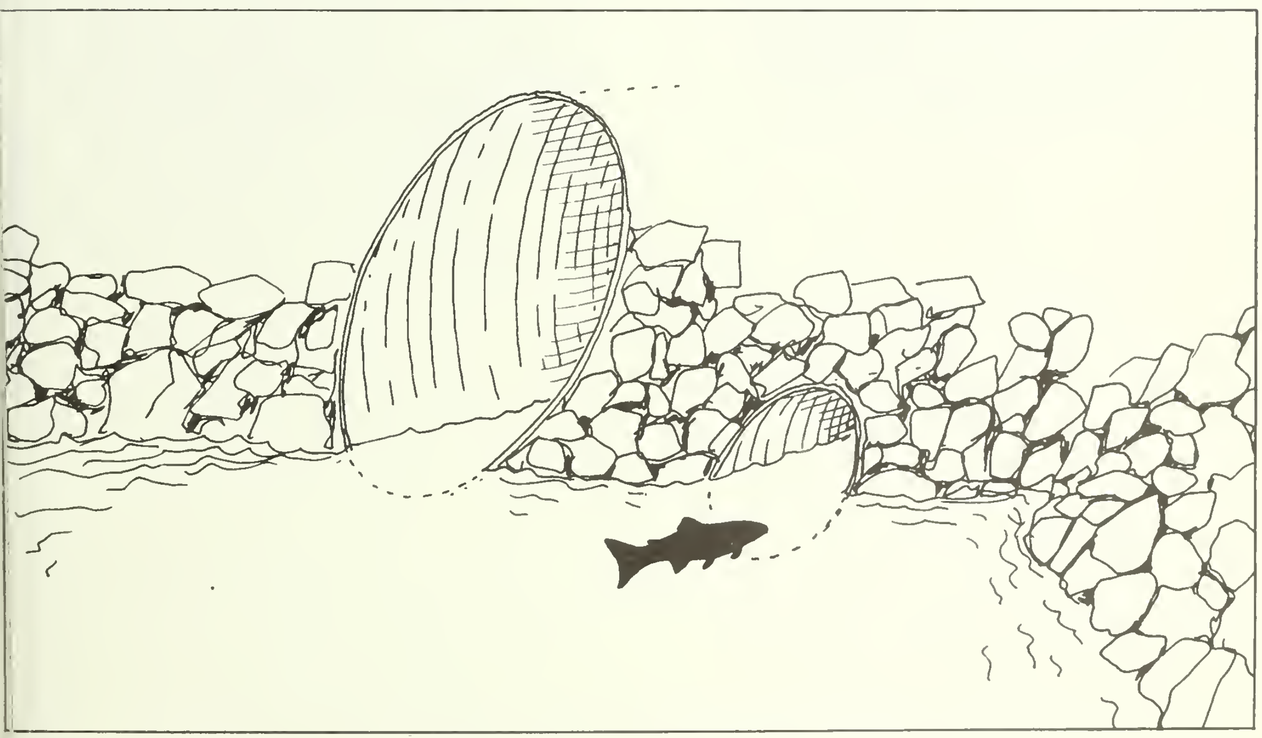
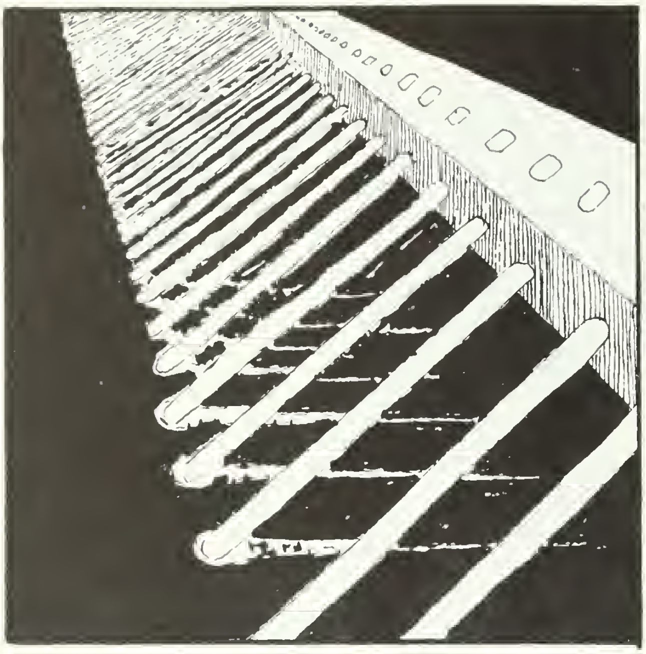


Figure 7--Fish passage may be provided in streams that have wide ranges of flows by providing multiple culverts.



STRUCTURES FOR DEBRIS CONTROL

The use of debris-control structures--such as trash or debris racks--is growing in western forests. A partial reason is the increased cost of replacing culverts and washed-out roadways; trash racks are often mandated by forest practice regulations.

Unfortunately, trash racks are detrimental to fish passage. The same freshets that often bring debris downstream are those in which many fish can move up to spawning areas. Although the protected culvert may not be a velocity or outfall barrier, a debris-laden trash rack is almost always impassable to fish. Debris-catching structures on streams used by migrating fish should be avoided.

To compensate for the loss of culvert protection from a debris-catching structure, the culvert should be large enough to let the debris pass through it. Passing debris through the culvert is as valid an alternative as intercepting it above the inlet, and this alternative should not be overlooked. Of course, increasing the culvert diameter adds to its cost, and sometimes increasing the diameter may not be practical. On the other hand, when debris can be passed through the structure without clogging, maintenance costs will be lower than when debris is intercepted and must then be removed.

SUMMARY

Forest road systems, along with other forest-management activities, can adversely affect a stream's ability to provide spawning and rearing habitat for anadromous fish. Guidelines are available for road construction and maintenance with minimal impact on anadromous fish habitat. Properly designed and placed culverts and debris-control structures can also help to minimize the impacts on fish habitat of forest road systems.

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Experiment Station

General Technical
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PNW-110

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Planners Guide for Estimating Cost Per User-Day of Proposed Recreational Facilities

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Experiment Station, Portland, Oregon.

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he absence of prices for nonmarketed oor recreational services provided by ic agencies, it is not possible to do a lete benefit-cost analysis for proposed lities for recreation. Good information he cost of providing recreational ices to the public is nonetheless impor- . This paper provides a step-by-step edure that recreation planners can use stimate the cost per user-day for osed recreational facilities.

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nits that measure recreational use.

The primary purpose of this paper is to show how to estimate costs per unit of recreational service. The unit used here is the recreational-visitor-day (RVD)--use of a recreational area for 12 person-hours; it may be 1 person for 12 hours, 12 people for 1 hour, or any equivalent combination. This approach is applicable to many kinds of recreational facilities, but the discussion relates specifically to developed campgrounds.

The secondary purpose of this paper is to present, for comparison purposes, costs per RVD for some existing USDA Forest Service campgrounds in Oregon and Washington. With this information, the planner can compare the cost of camping services to be provided by a proposed campground with the cost of camping services provided by comparable campgrounds in the region or with the cost for other types of campgrounds. These costs can be the basis for more elaborate benefit-cost analyses that may be required when public agencies plan their budgets.

Estimating Costs

The costs of a proposed campground will be figured in two parts: capital investment, and operation and maintenance. Figure 1 is a worksheet for estimating costs of capital investment. Capital costs must be separated by year so that they can be adjusted to a common year by adding interest charges. The common year is the year prior to the first full season of public use of the facility. Costs to be included are those that are incurred only if the project is undertaken. Costs that would be incurred whether or not the project is undertaken should not be included. Costs of vehicles, vehicle accidents, travel time, training, supervision, and other incidental costs of the project should be included. The one major item that should not be included is assessments against the project for general administration or overhead. Although these costs are commonly charged against projects, costs of general administration would not be eliminated by omitting the project and are, therefore, not attributable to the project. Other costs that should be omitted are planning costs that occur before the decision to undertake the project. These costs, like overhead, are incurred whether or not the project is completed. For this analysis, inflation can be recognized by using cost rates that are anticipated for the year in which the major construction occurs. Contributed materials should be valued at their fair market value because they could be put to an alternate use in which they would provide full value to society. Contributed labor is probably best valued at the minimum wage rate. The rationale is that the alternate use of much of that labor would be in jobs that pay fairly low wages.

Figure 2 is a worksheet for estimating t costs of operation and maintenance. Thes costs should be average annual estimates over the life of the project. Cost rates should be for the same year as the cost rates used in estimating the capital cos Contributed materials and labor should b valued in the same way as for capital investment items.

The next step is to estimate the recreational use that the facility will genera There is no "formula" for making this estimate. The planner can only look at t available information and make a judgmen about future use. The level of use of similar facilities in the same general a may be most useful. The attributes of th proposed facility, however, may have an important effect. A destination campgrou will typically receive more weekday use will have a higher total use than a campground used primarily on weekends. Other sources of data that may be useful are State comprehensive outdoor recreation plans and River Basin Commission reports These sources often have estimates of projected levels of recreational use and potential needs by counties or planning areas. Figure 3 provides a systematic wa to develop estimates.

	Cost and years prior to public use				
	5th	4th	3d	2d	1st
reconstruction costs:					
Environmental assessment					
Site survey					
Design					
Feasibility analysis					
Vegetative treatments					
Contract preparation					
Other					
onstruction costs:					
Clearing and grading					
Roads, spurs, and barriers					
Water development and distribution					
Sanitation					
Signs and bulletin boards					
Visitor information facilities					
Electrical connections					
Fee collection facilities					
Camp unit facilities					
Trails					
Contract administration and inspection					
Other					
tal capital investment by year					

e 1.--Worksheet for estimating costs of capital investment.

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Fee collection facilities					
Camp unit facilities					
Trails					
Contract administration and inspection					
Other					
tal capital investment by year					

e 1.--Worksheet for estimating costs of capital investment.

Average annual fixed costs:

Annual opening and closing	________
Scheduled maintenance	________
Other	________

Average annual variable costs:

Cleaning	________
Maintenance dependent on occupancy	________
Collection of fees	________
Vandalism	________
Law enforcement	________
Contacts with visitors	________
Utilities	________
Other[1]	________

Total average annual costs of operation and maintenance ________

[1]If road maintenance or fire patrols in the vicinity of the facility will be increased because of the project, these increased costs should be included in costs of operation and maintenance.

Figure 2.--Worksheet for estimating costs of operation and maintenance.

ımber of units of facilities; e.g., number of campsites or
cnic units ______________

ımber of user-units of recreational use per unit of facilities
r day with full occupancy ______________

ımber of days in season of use ______________

ıeoretical seasonal capacity (item 1 x item 2 x item 3) ______________

oportion of full occupancy[1] ______________

stimated average annual user-days (item 4 x item 5) ______________

the proportion of full occupancy can be estimated more readily by separating days of peak use the remainder of the season, do steps 3-6 separately for days of peak use and other days and he results for estimated average annual user-days.

re 3.--Worksheet for estimating amount of recreational use.

inal step is to use figure 4 to ute the estimated cost per user-day. , transfer the total costs of capital stment by year to the worksheet. These are multiplied by the cost adjustment rs from table 1 to include interest es to adjust them to the year prior to irst full season of public use. The is entered on line 1 and is then rted to an equivalent annual cost over ife of the facility by multiplying the by the appropriate capital recovery plier from table 2. This equivalent l cost is the amount that would have paid annually over the life of the ity to recover the initial investment nterest on the investment. To this l cost must be added the average l costs of operation and maintenance t the total average annual cost for ampground. The cost per RVD is ned by dividing the total average l cost for the campground by the ge annual RVD's estimated for the round.

Year prior to public use	Total capital investment[1]	Cost adjustment factor[2]	Equivalent cost[3]
(1)	(2)	(3)	(4)
5th	______	______	______
4th	______	______	______
3d	______	______	______
2d	______	______	______
1st	______	1.00	______
		Total	______

1. Equivalent total construction cost for the year prior to first full season of public use ______
2. Capital recovery multiplier ______
3. Equivalent annual cost (item 1 x item 2) ______
4. Average annual operation and maintenance cost ______
5. Total average annual cost (item 3 + item 4) ______
6. Estimated average annual user-days[4] ______
7. Cost per user-day (item 5 ÷ item 6)[5] ______

[1] From capital investment worksheet.
[2] Factor to carry cost at compound interest to 1st year prior to use.
[3] Column 2 x column 3.
[4] May be in recreation-visitor-days or other user-units.
[5] The annual cost per unit of facilities or per unit of theoretical capacity could be determined by dividing the total average annual cost (item 5) by the units of facilities or units of theoretical capacity.

Figure 4.--Worksheet for estimating costs per user-day.

e 1--Cost adjustment factors

r to ic	Interest rate (percent)					
	5	6	7	8	9	10
	1.216	1.262	1.311	1.360	1.412	1.464
	1.158	1.191	1.225	1.260	1.295	1.331
	1.102	1.124	1.145	1.166	1.188	1.210
	1.050	1.060	1.070	1.080	1.090	1.100
	1.000	1.000	1.000	1.000	1.000	1.000

e 2--Capital recovery multipliers[1]

s	Interest rate (percent)					
	5	6	7	8	9	10
	0.096	0.103	0.110	0.117	0.124	0.131
	.080	.087	.094	.102	.110	.117
	.071	.078	.086	.094	.102	.110
	.065	.073	.081	.089	.097	.106
	.061	.069	.077	.086	.095	.104

e formula for this table is:

$$CRM = \frac{i(1+i)^{n}}{(1+i)^{n-1}} ;$$

c CRM = capital recovery multiplier;
i = interest rate as a decimal--i.e., 7 percent = 0.07; and
n = number of years facilities will be used.

Using the Results

The cost per RVD developed here is based on average annual costs of operation and maintenance and average annual levels of use. If the annual level of either of these is skewed heavily toward the early part or the late part of the life of the facility, the estimated cost will be biased. This approach can still be used by using the annual figures, but that goes beyond the scope of this paper.

The cost per RVD omits the opportunity costs of using the land for a campground. The opportunity cost is the value of other benefits that are forgone when the land is used for a campground. For example, if the campground is on productive timberland, some timber harvest may be forgone both on the campground area and on a buffer area. A careful treatment of opportunity costs would make the analysis too cumbersome for general application by recreation planners. The opportunity cost of forgone timber harvest was, however, only a small part of the total cost of USDA Forest Service campground costs according to one study.[1]

[1]Kenneth C. Gibbs and Willen W. S. van Hees. 1978. U.S. Forest Service campground management in Region 6: A cost analysis. Report on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Table 3 is provided so that costs you estimate can be compared with the estima cost per RVD from a sample of 111 USDA Forest Service campgrounds in Oregon and Washington. These costs are not the actu historical costs. They are estimates of what the cost would have been if the campgrounds had been constructed in 197 and the average annual use was the 1977 level of use. These figures could be updated to estimate costs based on construction in the current year by multiplying the cost by the proportionat change in an appropriate cost index.[2] This would provide the most meaningful comparison of proposed campgrounds and existing campgrounds. Differences in cos could then be traced to their sources. Possible sources of significant differen in costs include: (1) standards of desig (2) site development costs because of terrain, soil, etc.; (3) access; and (4) the level of use.

[2]Cost indexes for "buildings" and "construction" are published quarterly for U.S. cities in the "Engineering News-Re (issued weekly by McGraw-Hill, Inc.). T multiplier is the index for the current year divided by the index for 1977.

e 3--Estimated cost per recreation-visitor-day (RVD) for
nple of USDA Forest Service campgrounds in Oregon and
ington[1]

erience evel[2]	Capital cost	Operation and maintenance costs	Total cost
		Dollars	
1	0.13	0.14	0.27
2	.71	.45	1.16
3	1.05	.52	1.57
4	.81	.45	1.26
5	2.03	.79	2.82
ge	.92	.48	1.40

are from Gibbs and van Hees (unpublished report on file
c. Northwest For. and Range Exp. Stn., Portland, Oreg.).
for construction are based on the estimated cost of
ructing an identical facility on an identical undeveloped
in 1977. Recreation-visitor-days are based on 1977 data
the RIM (Recreation Information Management) file. Capital
are amortized over an assumed 20-year life for the camp-
d at a real rate of interest of 6 percent. If the assumed
for the campground were 30 years, the capital costs/RVD
be approximately 16 percent lower and the total cost/RVD
be reduced by the same dollar amount as the capital
.

Forest Service campgrounds are classified by
rience level"; level 1 provides the most primitive
ng experience.

The interest rate used in the cost figures is 6 percent, and your costs should be estimated at 6 percent for comparison. If the real rate of interest specified for planning purposes for your agency is different, you will want to also make cost estimates at the specified rate.

The approach presented here uses the economics profession's approach of measuring costs in terms of costs to society. This is the most defensible basis for comparisons for a public agency even though the costs included do not correspond exactly to the dollars that must be budgeted. Dollars requested in the budget should exclude the value of contributed materials and labor and should include general administration charges that will be taken out of budgeted funds. Budgets can be based on the cost level for a particular year or on estimated inflated costs, depending on agency policy.

GPO 991-327

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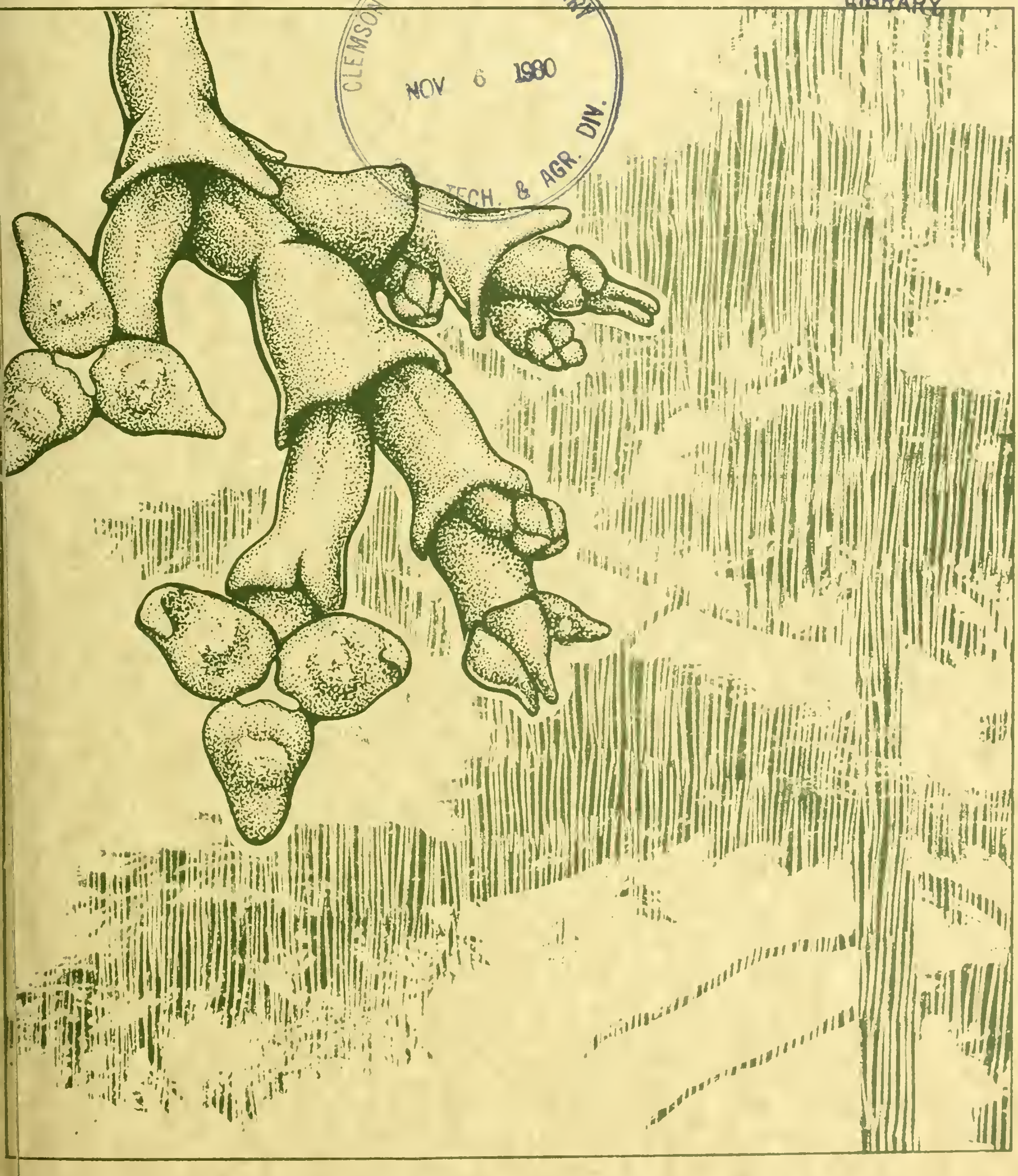
eptember 1980

Dwarf Mistletoe and Host Tree Interactions in Managed Forests of the Pacific Northwest

Donald M. Knutson and Robert Tinnin



Authors

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Abstract

Dwarf mistletoes in the Pacific Northwest infect true firs, larch, pine, Douglas-fir, and hemlock. Forty-one percent of all stands east of the crest of the Cascade Range and 10 percent of west-side stands are infected. General characteristics of dwarf mistletoe are discussed, including mortality and growth losses, rate of spread within a tree and within stands, relation of site class and growth loss, and the effect of management activities.

Contents

troduction

arf mistletoes[1] are parasites of conif-
ous species, primarily of the family
naceae. The group has many common fea-
res, and thus some general principles
eful to forest management can be stated.

e important common biological features
r dwarf mistletoes in the Pacific
rthwest are that they all:

- are flowering parasites that remove and use organic and inorganic nutrients and water from host trees.
- produce sticky seeds in the fall and shoot them through the air. Some of the seeds stick to the branches of trees on which they were produced or on branches of nearby trees.
- are somewhat host specific. That is, each kind of dwarf mistletoe (eight in the Pacific Northwest) can parasitize only a certain set of coniferous species.

one sense, dwarf mistletoe should be
atively easy to control because survival
ends on living trees; removing trees
troys the mistletoe. The association of
tern conifers and dwarf mistletoe is an
ient one, however, dating at least back
the Pleistocene. Since then, the dwarf
itletoes have spread throughout the West
n adapted to their hosts; currently
0 percent of all stands east of the crest
f the Cascade Range are infected, and
0 percent of west-side stands are infected.

agement activities have also influenced
itribution of dwarf mistletoe. For many
rs, stands were thinned to 12-foot
cing--almost the optimum spacing for
tletoe spread from tree to tree. Thus,
revious management choices have probably exacerbated the problems in second-growth stands, which will require additional management in the next 20 years. Seriously infected stands often produce only two thirds of their potential volume. We can minimize these problems by basing current management prescriptions on the best information available on the biology of dwarf mistletoe.

These are general statements about dwarf mistletoe. If, after reading this report, you need more specific advice, we recommend that you contact the Division of Forest Insect and Disease Management at Region 6 headquarters in Portland, Oregon. Additional information useful to field managers is also available in a report by Scharpf and Parmeter (1978).

Field personnel working in the infested stands are best able to confirm or modify the general principles we have stated about dwarf mistletoe. We encourage all readers to tell us how to improve them.

---

[1] Scientific names of all plants mentioned
re in appendix table 6.

Reproduction, Seed Characteristics and Effects of Broom

Dwarf mistletoe spreads by seeds produced on female plants. Pollen from male plants is transferred by wind and by insects to female flowers (Penfield et al. 1976). Seed maturation takes two seasons. Seeds ripen in August and September and are explosively cast into the air; they have a sticky coating (viscin) that can hold them to almost any surface they strike. Seeds that adhere to susceptible host trees overwinter there and can infect the wood when growth begins in spring. Typically, seeds land on needles and, when wetted by winter rains, slide down to the twig. Mistletoe seeds cannot infect needles or older twigs that have thick bark. The probability of infection of a given seed is low; less than 5 percent of all mistletoe seeds on ponderosa pine in Arizona, New Mexico, and Colorado actually survived, infected, and produced new plants (Hawksworth 1961). Dwarf mistletoe seeds are frequently eaten by insects, killed by fungi, or simply removed by snow, rain, or wind (Wicker 1967).

Dwarf mistletoes often stimulate adventitious budding of host trees. These buds produce a dense growth called a witches' broom, which reduces tree growth and vigor. In heavily infected ponderosa pine, brooms caused more reduction in diameter growth than branch infections (broomy trees: 59 percent reduction; nonbroomy trees: 14 percent reduction); no difference was noted in lightly infected trees (Hawksworth 1969). In another report, the diameter growth of a Douglas-fir increased after a large broom was removed (Weir 1916). In lodgepole pine, heavy brooming did not affect growth more than a comparable degree of individual branch infections (Baranyay and Safranyik 1970).

Common Hosts Important To Forest Managers

The common hosts important to forest managers in the Pacific Northwest are larch, ponderosa pine, lodgepole pine, Douglas-fir, western hemlock, mountain hemlock, and the true firs (table 1).

Dwarf mistletoes are largely specific t one or two hosts. Infections of other hosts are called cross-infections. Cro infections can be locally severe, but a not usually a management problem.

Locally severe cross-infections have be noted in the following locations:

> Hemlock dwarf mistletoe on shore pine British Columbia (Smith, 1976).
>
> Hemlock dwarf mistletoe on the true fi in the Cascade Mountains of Oregon an Washington, principally in the Willam- ette, Mt. Hood, Gifford Pinchot, Mt. Baker, Snoqualmie, and Olympic Nation Forests (personal communication, J. Hadfield, USDA For. Serv., Portland, Oreg.). The mistletoe causes little damage to the true fir but readily mo back to the hemlock understory.
>
> Larch dwarf mistletoe infects grand f subalpine fir, and lodgepole pine, pr duces viable seed, and reinfects larch the Colville National Forest, Washing (personal communication, O. Dooling, (For. Serv., Missoula, Mont.).

Other locally severe cross-infections m occur. Managers should remain alert to potential for such infections in their districts.

Genera of the Cuppressaceae (in North America) and Taxodiaceae are entirely immune: Chamaecyparis, Cuppressus, Juniperus, Libocedrus, Thuja, and Sequo

able 1--Species of dwarf mistletoe and their common and infrequent hosts in the acific Northwest (adapted from Hawksworth and Wiens 1972)

warf mistletoe	Hosts	
	Common	Infrequent
ouglas-fir	Douglas-fir	Grand and subalpine fir
emlock	Western and mountain hemlock	Grand, noble, Pacific silver, and subalpine fir; Brewer spruce; lodgepole, western white, and white bark pine
arch	Western larch	Subalpine fir; Englemann spruce; lodgepole, ponderosa, and white bark pine; mountain hemlock
odgepole pine	Jack and lodgepole pine	Limber, ponderosa, and white bark pine
ed fir	California red fir (noble fir)[1]	None
gar pine	Sugar pine	Brewer spruce and western white pine
stern	Jeffrey, knobcone, and ponderosa pine	Lodgepole pine
ite fir	Grand and white fir	Pacific silver and subalpine fir

[1] Designation in question.

Distribution and Volume Losses

Distribution and Frequency

The dwarf mistletoes are widely distributed in Western North America from Guatemala (on pine) to Alaska (on hemlock). Six species are widely distributed in the Pacific Northwest (fig. 1). Dwarf mistletoe was found on 23 percent of almost 17,000 forest inventory plots in Oregon, Washington, and California (Bolsinger 1978). In Oregon and Washington, 41 percent of the stands east of the Cascade crest and 10 percent of those west of the Cascade crest were found to be infected.

Douglas-fir stands were the most frequently infected among types of conifer stands in the three west coast states (table 2). The percentage of this forest type actually infected was lowest however, because the Douglas-fir forests west of the Cascade crest are largely free of dwarf mistletoe (Tinnin and Knutson 1973).

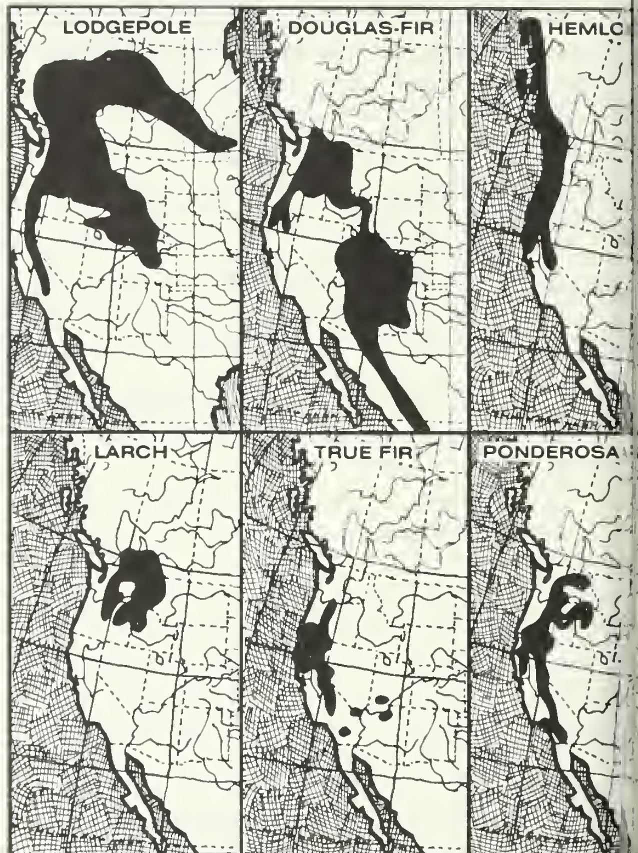


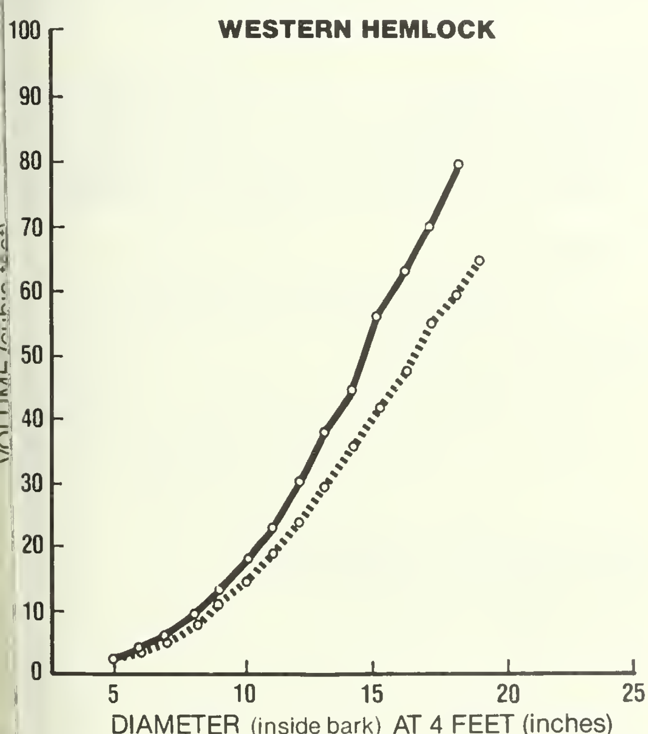
Figure 1.--General distribution of the principal dwarf mistletoe species foun the Pacific Northwest (adapted from Ha worth and Wiens 1972). Outline map us with permission of the Denoyer-Geppert Company, Chicago.

Table 2--Percentage of commercial forest infected with dwarf mistletoe in California Oregon, and Washington (adapted from Bolsinger 1978)

Host	Area infested with dwarf mistletoe	Portion of forest with infected tr
	Million acres	Percent
Douglas-fir	3.6	13
Firs, true	1.9	21
Hemlock, mountain and western	1.3	21
Larch, western	1.0	47
Pine, Jeffrey and ponderosa	3.2	26
Pine, lodgepole	1.5	42

olume Reductions

›lume losses can be large. Smith (1969) ›timated a volume loss of 37 percent over 2-year period for western hemlock. ›cause yield reductions result from a ›mplex of interacting factors, however, ›ecise predictions are difficult. Growth ›ductions are influenced by amount of ›fection, how long a tree has been ›fected, location of infections in the ›own, age of the tree, the site, and stand ›nsity. The longer a tree is infected, ›r example, the greater its volume is ›duced compared with a healthy tree (fig. .



F›gure 2.--Volume loss from dwarf mistletoe i›creased with the duration of infection (›mith 1969). Data from Vancouver Island, B›itish Columbia.

Mortality

Mortality is higher in infested stands. Forest survey data from the Okanogan National Forest showed that over a period of 10 years Douglas-fir on infested plots had a mortality rate 10 percent higher than on uninfested plots (Knutson, unpublished data on file at the Forestry Sciences Laboratory, Corvallis, Oregon 97331). Mortality in infested lodgepole pine stands in Alberta ranged from 0 to 26 percent higher than in healthy stands, depending upon stand age, level and duration of infection, and site (Baranyay and Safranyik 1970).

Mortality rates are related to severity of infection; severely infected trees are most likely to die (table 3). Higher mortality is associated with low vigor trees (table 4). After dwarf mistletoe has caused a general decline in host vigor, death is often caused by Armillaria mellea root rot or bark beetle infestations (Knutson, unpublished data on file at the Forestry Sciences Laboratory, Corvallis, Oregon 97331).

Table 3--Percent of dead ponderosa pine and Douglas-fir in New Mexico by infection classes (from Hawksworth and Lusher 1956)

Dwarf mistletoe rating	Ponderosa pine	Douglas-fir
	Percent	
0 (no infection)	1	1
1	1	1
2	2	4
3	4	8
4	9	13
5	12	24
6 (severe infection)	38	45

Table 4--Mortality of ponderosa pine over a 40-year period in California as related to tree vigor (from Wagener 1961)

Tree vigor	Mortality
	Percent
Vigorous	0
Thrifty	5
Moderate	42
Poor	100

Spread Of Infection Within A Tree

Rate of Vertical Spread

New mistletoe infections develop upward i a tree at rates of about 1-2 feet or less per year (table 5). If tree height growth exceeds the rate of spread of the mistle- toe, a relatively infection-free crown ca develop in time.

Table 5--Average rates of vertical sprea of dwarf mistletoe

Species	Vertical distance/year	Reference
	Feet	
Western hemlock (British Columbia)		Richardson and Van der Kamp (1[illegible])
Dense stand (304 trees/acre)	1.0	
Open stand (101 trees/acre)	2.1	
California red fir (California)	< 0.3	Scharpf a Parmete (1976)

Potential for Infection of Upper Crown

Mistletoe plants in the upper crown of hemlock produce the most aerial shoots (Smith 1969) and are in a position for g seed production (Richardson and Van der [illegible] 1972) and distribution. Seeds produced i the upper crown thus have a high potenti to produce other infections.

;pread Of Infection
'hrough Stands

rom Stand Boundaries

ıfection from residual stands into regen-
:ated clearcuttings of the same species
ın occur many feet from the stand margin
'ig. 3). Dwarf mistletoe seeds have been
ɔund 145 feet from the edge of the
esidual stand, but 20 to 40 feet is usual
Scharpf and Parmeter 1967). The average
ate of spread through young, even-aged
:ands was 1.2 feet per year in very dense
:ands, and 1.7 feet per year in open
:ands (Hawksworth 1958, 1961) because of
ıe screening effect of the tree crowns in
ducing seed movement. When the foliage
ponderosa pine trees is 8-15 feet apart,
acing is optimum for transfer of dwarf
stletoe seed from tree to tree (Strand
74).

even crown height (fig. 4) has an effect
milar to reduced crown density, allowing
vement of mistletoe seeds from tree to
ee (Hadfield and Russell 1978, Parmeter
78).

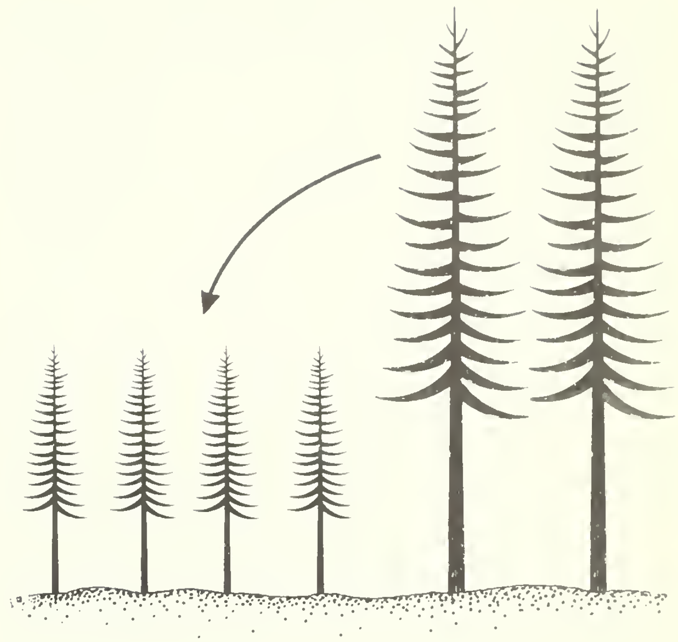


Figure 3.--Infection of regenerating clearcuttings from infected trees along the boundary.

b Understory From Overstory

Ifection of understory from overstory
:ees occurs whenever susceptible young
:ees grow under infected trees. This
ɔcess is especially important to forest
ınagers when infected trees remain after
ırvest. Predictably, the density of dwarf
ıstletoe seeds drops rapidly with distance
fɔm these source trees (figs. 5 and 6), as
les the number of mistletoe plants in the
ıderstory that result from the overstory
sed source (Smith and Baranyay 1970).

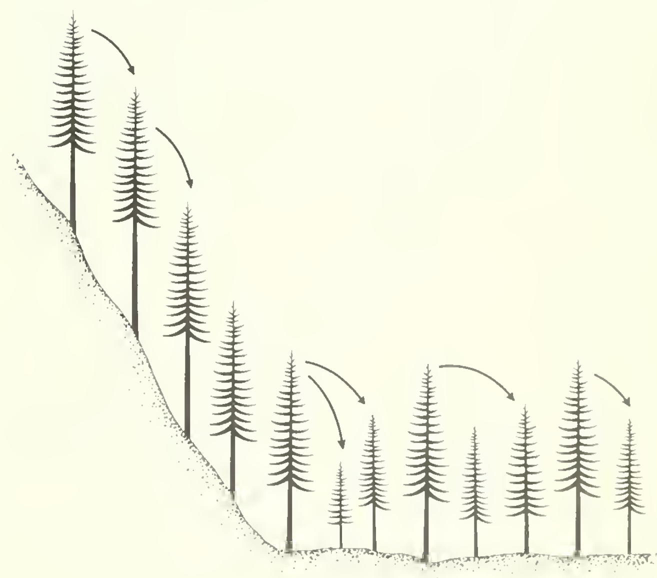


Figure 4.--Infection of trees on slopes and in uneven-aged stands.

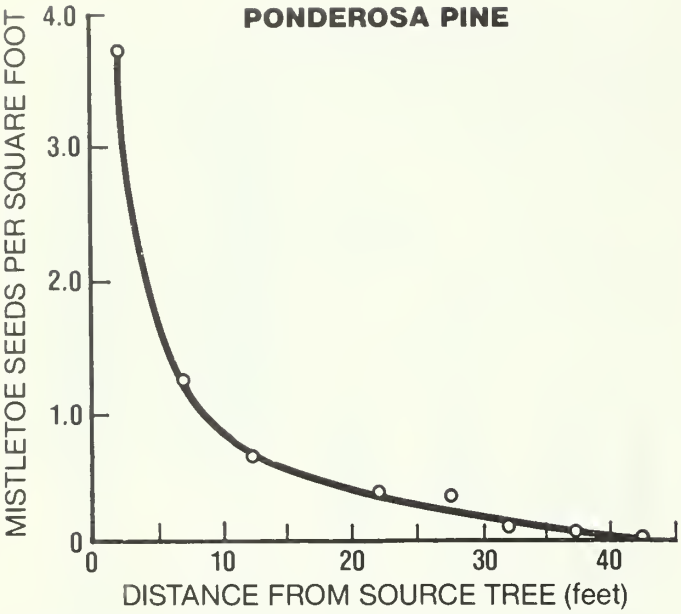


Figure 5.--Density of dispersed seeds of southwestern dwarf mistletoe relative to distance from the source tree (Hawksworth 1961). Data from Colorado.

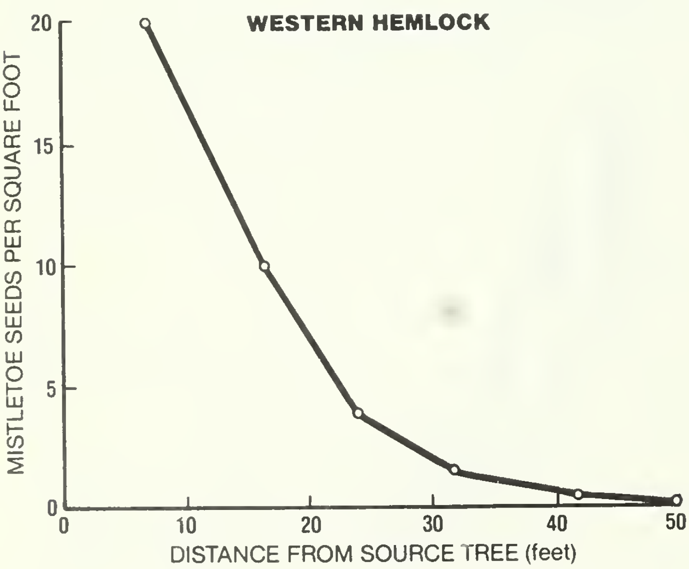


Figure 6.--Density of dispersed seeds of hemlock dwarf mistletoe relative to distance from the source tree (Smith 1973). Data from British Columbia.

In the presence of an infected overstory the percentage of understory trees infec increases with their height and diameter (figs. 7 and 8). The larger the tree, t greater is the chance of its being infec because it is more likely to be struck b dwarf mistletoe seed. Also, large trees tend to be older and thus exposed for a longer time.

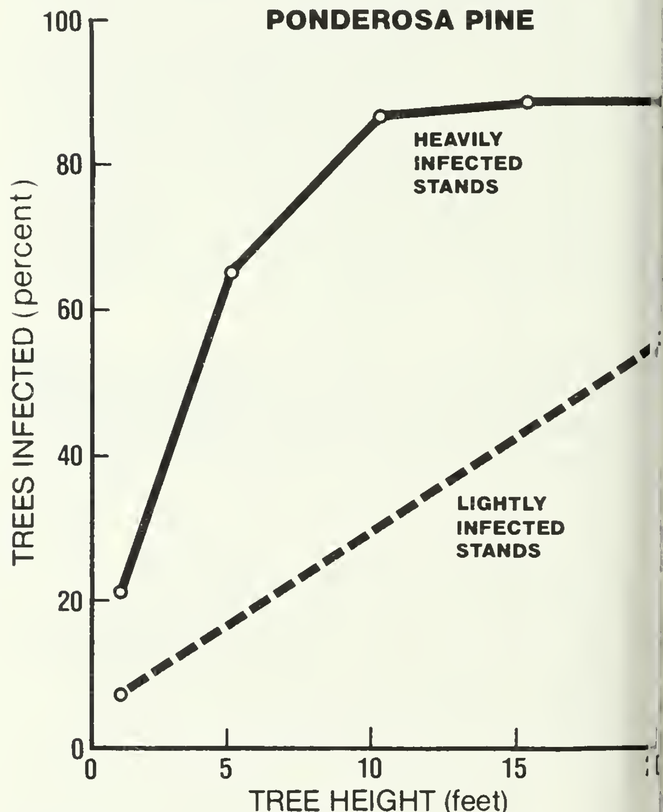
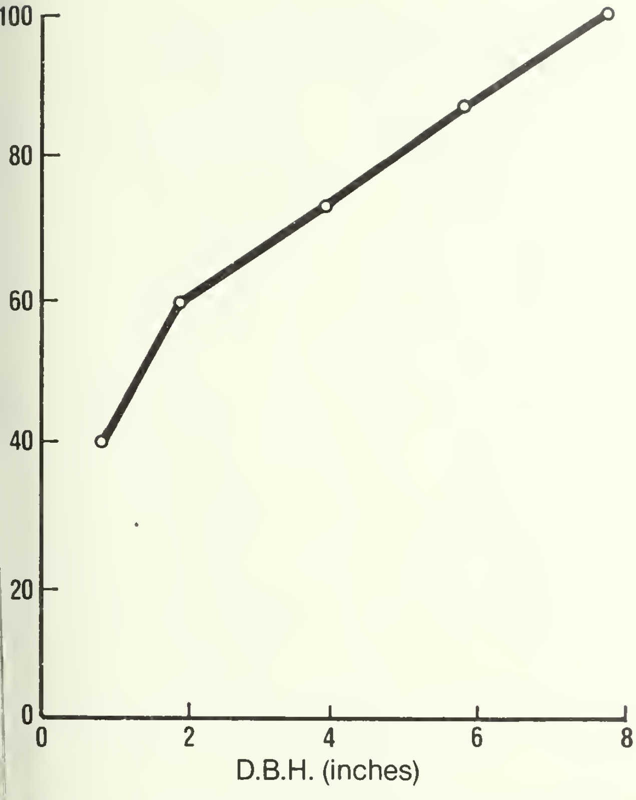


Figure 7.--Percentage of infected ponde pine trees in the understory related to tree age (Childs 1963).



gure 8.--Percentage of infected ponderosa ne in the understory related to diameter ass (Shea 1964). Data from Oregon.

Animals

imals, especially birds, are important in ng-distance spread of dwarf mistletoe eds (Hudler 1976, Zilka and Tinnin 1976), t infrequently. Reducing dwarf mistletoe ed production will reduce the probability f spread by animals.

Latent Infections

Many mistletoe seeds that infect host trees do not readily produce aerial shoots. These undeveloped sites are called latent infections. The cause of this phenomenon is unknown. We do know that the more advance forms, such as dwarf mistletoe of Douglas-fir, are the least likely to produce aerial shoots. Latent infections are most likely to occur on trees that are severely stressed, such as those in dense, suppressed stands or trees that already have many mistletoe plants. For example, an apparently uninfected, suppressed Douglas-fir tree may have several latent infections, or a small, suppressed ponderosa pine may have 10 obvious mistletoe plants but actually have 20 infections. About a third of all infections are latent in unthinned, infested stands. If 300 apparently infected trees occur per acre, the actual number infected will be about 450 in stand densities from 500 to 3,000 stems per acre (Childs 1963, Shea 1964). Latent infections may remain hidden for years or become active within a year; they produce aerial shoots if growing conditions of the tree improve, as with thinning. Shea (1964) thinned suppressed, stagnant ponderosa pine saplings and attempted to prune out all mistletoe infections. Fifty percent of the leave trees required additional pruning. The more open the stand, the less likely were latent infections.

The more heavily infected an individual tree, the more likely it will have latent infections (Childs 1963). To determine whether understory trees are infected, look for aerial shoots, because prominent brooms often do not develop in young trees. The more suppressed the stand, the fewer aerial shoots will be produced. Some commercial species in the Pacific Northwest naturally produce aerial shoots more readily than others, whether or not trees are suppressed. True fir and hemlock dwarf mistletoe are the most likely to have aerial shoots; ponderosa pine, western larch and lodgepole pine are intermediate in aerial shoot production. Douglas-fir dwarf mistletoe often produces very few aerial shoots.

After thinning, 90 percent of all latent infections will appear within 5 years--usually within 3 years (Shea 1964). At a second thinning between 5 and 10 years after the first, infected trees will become identifiable and can be removed.

Site Characteristics

Infection of hosts by dwarf mistletoe produces stress, which can combine with site-related stresses, such as availability of moisture and soil nutrients or severe winter conditions. Some known effects of dwarf mistletoe on trees are:

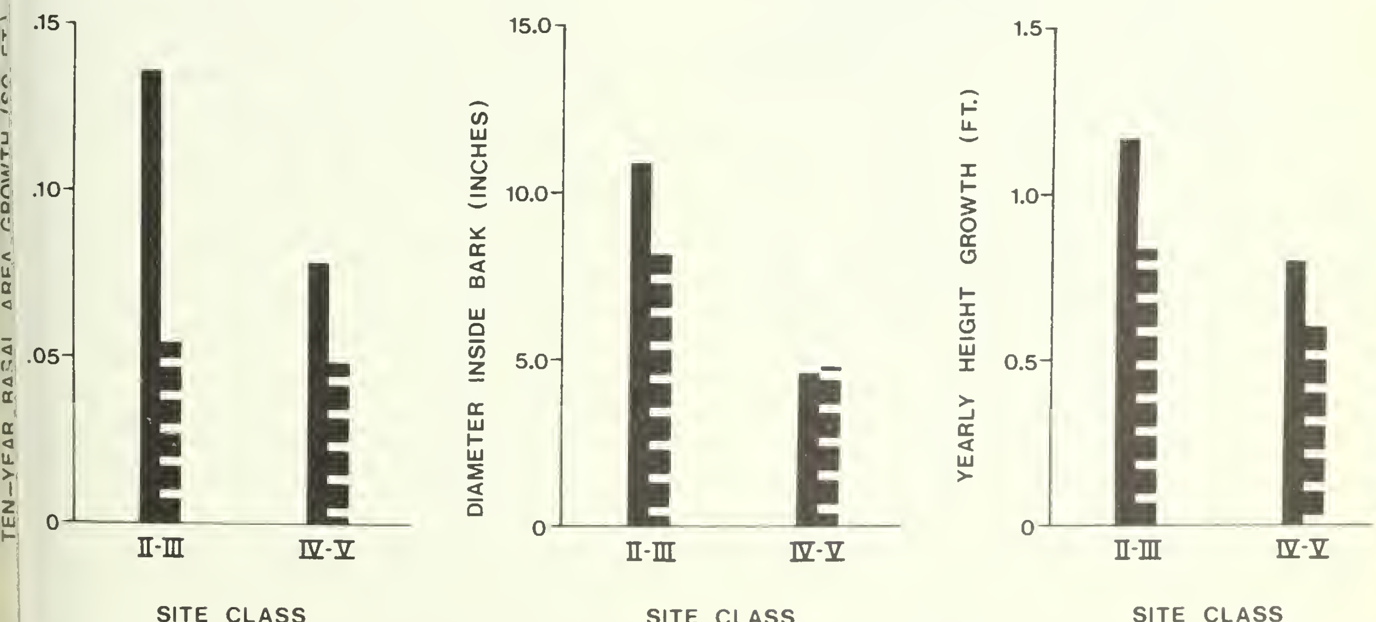
- Reduced root growth (Knutson and Toe 1973).
- Higher metabolic rates in infected t limbs (Clark and Bonga 1970).
- Movement of carbohydrates to the infection sites (Hull and Leonard 19
- Reduction of stored carbohydrates (sugars and starches) in host trees (Hull and Leonard 1964).
- Increased water stress of the host. Mistletoe can obtain water from the tree, even when the host xylem is un high water stress (Mark and Reid 197

The effect of mistletoe-induced stresses trees depends on the genetic variation i the tree's tolerance to infection and th number of visible and latent infections unit of crown. The interactions of site stresses and dwarf mistletoe stresses ar unpredictable and cause considerable variation from one area to another in th amount of damage to the host.

he vigor of the parasite is correlated ith host vigor: mistletoe growth is reater on healthier trees. In Colorado, or example, dwarf mistletoe of ponderosa ine had larger, more robust aerial shoots nd produced more seed on vigorous onderosa pine than on low-vigor trees. imilarly, the growth rate of its ndophytic system (that part of the mistle- oe plant in the phloem tissue of the tree) s nearly twice as rapid in the main stems f dominant as in suppressed trees. Broom ize increased most on the most vigorous rees (Hawksworth 1961). Similarly, true irs at high elevation with short-growing easons had smaller dwarf mistletoe plants ith fewer seeds than at comparable lower levation sites. This linkage of tree and arasite vigor can also be seen within a ingle tree, where established dwarf mistle- oe plants grow best and produce most seed t sites of highest nutrition (twig tips d near crown apex) and poorest in the ower crown and on the oldest limb wood.

warf mistletoe reduces tree growth most on ood sites, assuming the same sized tree d the same number of mistletoe plants per it of tree crown.

Heavily infected trees on good sites may grow better than uninfected trees on poor sites. Generally growth measurements (height, diameter, or volume) of infected trees are about 25 percent lower on good sites and about 10 percent lower on poor sites than comparable uninfected trees. The effect of dwarf mistletoe infection on tree growth on different sites is shown in fig. 9 for Douglas-fir in Montana (Pierce 1960). Management practices can have the effect of improving site quality. Fertilizing, watering, and reducing stocking improve growth of mistletoe plants already established in the tree. Conversely, infertile soils, high moisture stress, and dense stands decrease the vigor of mistletoe plants. These conditions influence tree and mistletoe alike; after a drought stress, infected lodgepole pine were less able to recover than were uninfected trees (Baranyay and Safranyik 1970).



Fgure 9.--Dwarf mistletoe reduced growth of Douglas-fir more on good sites than on por sites. Data from western Montana (Pierce 1960). Solid line = uninfected trees; boken line = infected trees.

Although thinning or fertilizing may promote growth of established mistletoe plants, establishment of new infection depends on foliar characteristics of the tree. If foliage is thin, mistletoe seeds can travel easily through the crown, infecting limbs within the tree and many seeds land on neighboring trees.

If tree foliage is dense, mistletoe seeds are often trapped by needles near the source (fig. 10). This reduces the rate of new infection in the distant part of the crown. Trees with sufficiently dense crowns can grow away from the mistletoe, especially if crown closure occurs and the lower, infected limbs become shaded. Mistletoe seed production is reduced and eventually the shaded limbs die.

Figure 10.--Dense crowns can impede the movement of dwarf mistletoe seeds upward.

Dynamic Relations With Host Trees

In any natural stand, the trees and mistletoe are related in a type of dynar equilibrium, which forest management activities, such as thinning or partial harvesting, modify. The vigor of the parasite is linked to host vigor: mistl toe growth is greater on healthier trees Management practices can indirectly impr the growth of mistletoe, so care must be taken to avoid that.

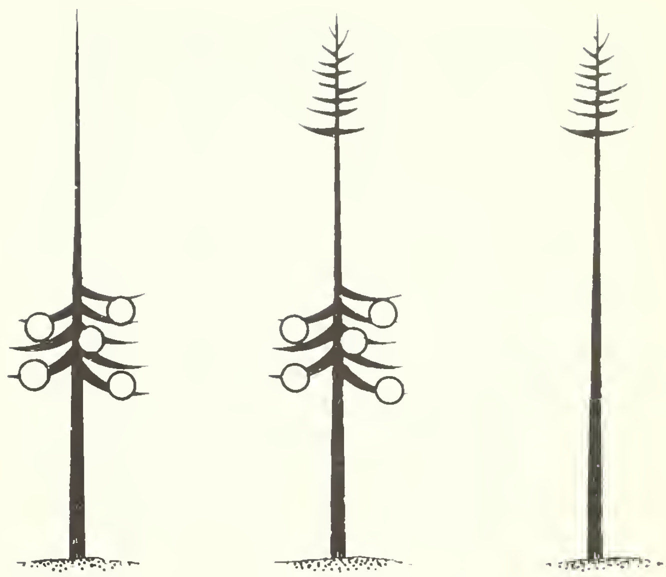
Management Favoring Trees

Activities that favor trees and are dele terious to dwarf mistletoe include:

- Removing infected overstory from den understory and thinning the understo leaving the most mistletoe-free trees with good crowns for crop trees.
- Maintaining mixed-species stands-- whether or not cross-infections occu
- Favoring tree species that are immun when thinning mixed stands, or favor species with the least amount of dwa mistletoe. For example, true firs m grow well when released, even with m infections throughout the crown (Sch and Parmeter 1976, Scharpf 1978). S species or some age classes (such as western hemlock in southwestern Oreg do not respond well to release with without dwarf mistletoe, and they ar poor choices for crop trees.
- Planting Douglas-fir under infected overstories of any other tree specie Douglas-fir is immune to all other mistletoes, and Douglas-fir mistleto is never a serious problem on any ot tree species.
- Favoring, among infected shelterwood leave trees, those without infection in the upper half of the crown. Not that determining whether mistletoe infections are present high in the crown is very difficult especially i species that do not always develop prominent brooms--such as hemlock, t fir and, sometimes ponderosa pine.

- Maintaining tightly closed canopies in western hemlock stands. This causes death of lower branches, which are usually the most heavily infected. Infected trees of all species are disadvantaged and will be eliminated from stands under conditions of high competition. Infected trees have poorly developed root systems and impaired photosynthetic apparatus compared with uninfected trees.
- Top-pruning, which allows infection-free crowns to develop (Knutson 1975). The pruning procedure is as follows (fig. 11):
  1. Remove all limbs from the top 10-15 feet of crown. The branches that remain may be infected (fig. 11a).
  2. In time, a new treetop develops. Mistletoe seeds shot from the lower crown have a low probability of hitting the small target of new top foliage (fig. 11b).
  3. After sufficient top has developed, remove the remaining lower branches. The result is a tree with very little mistletoe and healthy foliage (fig. 11c).

Traditional pruning is also helpful but often leaves infected limbs high in the crown, where they are apt to cause other infections and damage the host.



a b c

Figure 11.--Top-pruning to control dwarf mistletoe: A, remove all branches from top 10-15 feet of bole; B, allow new top growth to develop; and C, remove all old branches.

Management Favoring Dwarf Mistletoe

Activities favorable to dwarf mistletoe include:

- Partially removing the infected mature overstory. Mistletoe seed production will increase with improved nutrition of the infected leave trees. The open stand will promote regeneration, and the new trees--if of the same species--can become infected by the dwarf mistletoe seeds. In addition, increased mortality can occur in the remaining overstory trees; some heavily infected trees seem unable to adjust to release from competition.
- Leaving trees with mistletoe plants high in the crown. These plants will produce many seeds situated for efficient distribution. In addition, young thinned trees with mistletoe plants within 2 feet of the apical shoot of the tree tend to have a high rate of mortality.

- Spacing trees for optimum spread of mistletoe seeds between adjacent trees. "Step-laddering" (fig. 12) is slower in mixed-species stands. Hawksworth (1961) proposed a hypothetical relation between stand density and rate of spread of southwestern dwarf mistletoe (fig. 13). Although the position of the curve will vary from species to species, the shape of the curve should be approximately correct for other tree-mistletoe combinations. For ponderosa pine in Oregon, the highest probability of infection occurs when a mistletoe plant on one tree and foliage on another tree are 12 feet apart (Strand 1974).

Our statements about the dwarf mistletoes are a compromise between generality and precision. We have stressed generality at the expense of precision, because precision is both difficult to obtain and--although desirable--is not necessary for improved management of most infested stands. Research is continuing to obtain more and better information on the biology of dwarf mistletoes and on management of infested stands.

We encourage field managers to help us add to and improve the accuracy of these general principles.

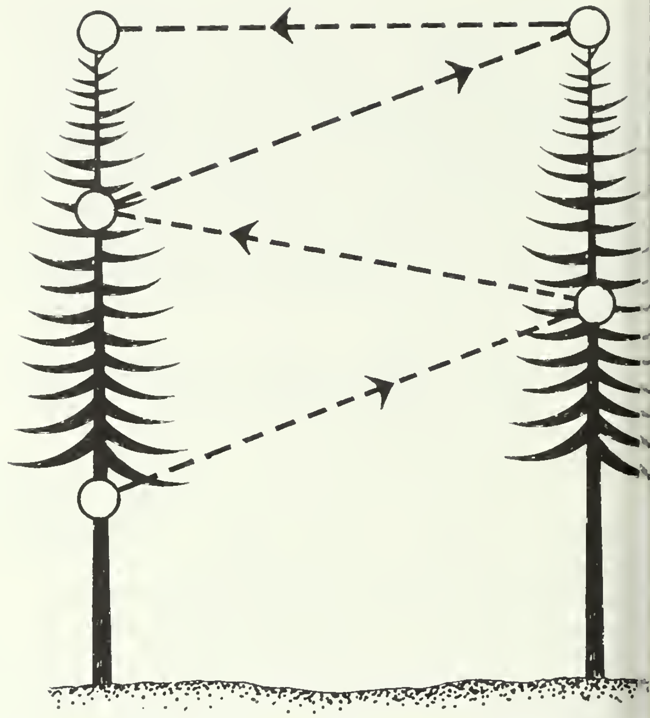


Figure 12.--Certain stand densities ca favor the vertical rate of spread of dwarf mistletoe.

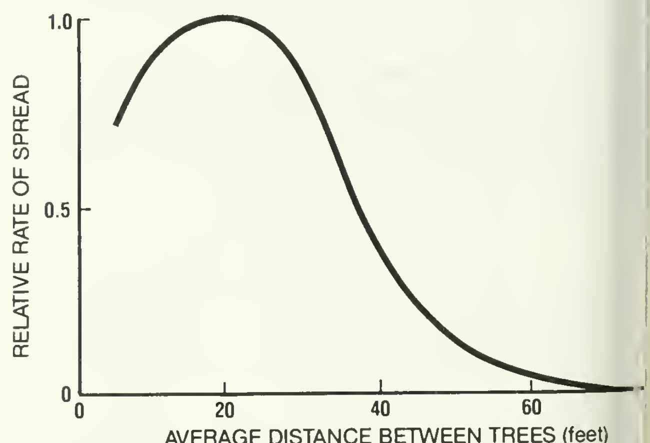


Figure 13.--Hypothetical relation of sta density to rate of spread of dwarf mist in ponderosa pine (Hawksworth 1961). Th curve will shift to the left for younge stands and to the right for older stands.

cknowledgments

appreciate the many contributions of orester Floyd Peterson (Rogue River tional Forest). His understanding of arf mistletoe and the management of fested stands have strengthened this nuscript.

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ppendix

ble 6--Common and scientific names of trees and dwarf mistletoes

mmon name	Scientific name
TREES	
uglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
r	
Grand	*Abies grandis* (Dougl. ex D. Don) Lindl.
Noble	*A. procera* Rehd.
Red, California	*A. magnifica* A. Murr.
Silver, Pacific	*A. amabilis* (Dougl.) ex Forbes
Subalpine	*A. lasiocarpa* (Hook.) Nutt.
White	*A. concolor* (Gord. & Glend.) Lindl. ex Hildebr.
mlock	
Mountain	*Tsuga mertensiana* (Bong.) Carr.
Western	*T. heterophylla* (Raf.) Sarg.
rch	
Western	*Larix occidentalis* Nutt.
ne	
Jack	*Pinus banksiana* Lamb.
Jeffrey	*P. jeffreyi* Grev. & Balf.
Knobcone	*P. attenuata* Lemm.
imber	*P. flexilis* James
odgepole	*P. contorta* Dougl. ex Loud. var. *latifolia* Engelm.
Ponderosa	*P. ponderosa* Dougl. ex Laws.
hore	*P. contorta* Dougl. ex Loud. var. *contorta*
ugar	*P. lambertiana* Dougl.
hite, western	*P. monticola* Dougl. ex D. Don
hitebark	*P. albicaulis* Engelm.
ruce	
rewer	*Picea brewerana* Wats.
ngelmann	*P. engelmannii* Parry ex Engelm.
DWARF MISTLETOES	
oglas-fir	*Arceuthobium douglasii* Engelm.
elock	*A. tsugense* (Rosendahl) G. N. Jones
ach	*A. laricis* (Piper) St. John
ogepole pine	*A. americanum* Nutt. ex Engelm.
e fir	*A. abietinum* Engelm. ex Munz f. sp. *magnificae* Hawksworth & Wiens
othwestern	*A. vaginatum* subsp. *cryptopodum* (Engelm.) Hawksworth & Wiens
ur pine	*A. californicum* Hawksworth & Wiens
estern	*A. campylopodum* Engelm.
hie fir	*A. abietinum* Engelm. ex Munz f. sp. *concoloris* Hawksworth & Wiens

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Department of
Agriculture

Forest Service

Pacific Northwest
Forest and Range
Experiment Station

General Technical
Report
PNW-112

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Wetwood in Trees: A Timber Resource Problem

J.C. Ward and W.Y. Pong

Abstract

Available information on wetwood is presented. Wetwood is a type of heartwood which has been internally infused with water. Wetwood is responsible for substantial losses of wood, energy and production expenditures in the forest products industry.

The need to evaluate these losses and to find ways to eliminate or minimize them is emphasized.

Because of increased interest in wetwood, excellent opportunities exist in initiating a comprehensive program of research. Both short and long-term studies are included in the program with the short-term studies answering the immediate utilization problems created by wetwood and the long-term studies directed at examining the causes of wetwood and its control and prevention.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.304 8 meter
1 cubic foot = 0.028 32 cubic meter
1 pound = 0.453 6 kilogram
1 pound/square inch = 0.070 38 kilogram/square centimeter
5/9(^{o}F-32) = ^{o}C

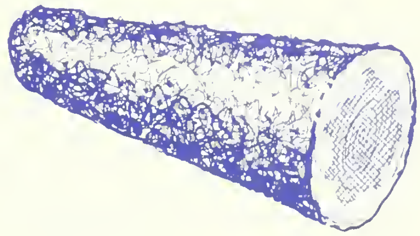
Contents

ntroduction

his paper summarizes available information
n the timber quality characteristic des-
ribed as wetwood. Included are some pos-
ible causes of wetwood, where it occurs in
rees, its properties, and the problems
ssociated with it. The need for research
o solve utilization problems associated
ith wetwood and the processing of logs and
roducts containing it is recognized.

th this report as a guide, a concerted
search effort directed at the problem of
twood can be organized. Such research
ll, in the short run, target in on and
ovide answers to wetwood-related proc-
sing problems presently plaguing industry
d, at the same time, build a base of sci-
tific knowledge with which to solve the
oblem of wetwood in timber stands.

Characteristics of Wetwood



Wetwood is a type of heartwood in standing trees which has been internally infused with water (64, 79, 142). Wood infused with water from an external source (e.g., logs exposed to spray, rain, or storage ponds) does not fit this definition. In some tree species, wetwood often has a water-soaked translucent appearance and is variously designated as water core, sinker heart, wet core, wet heart, and discolored wood. When frozen, the water-soaked wetwood appears as a distinct, hard, glossy surface on the ends of winter-cut logs of Scots pine (*Pinus sylvestris* L.) (117) and balsam fir (164).[1]

In other species, the typical water-soaked appearance may be absent. In this case, wetwood has the appearance of either normal heartwood or it has an unusually dark color. This dark color leads to the term "false" or "pathological" heartwood. Red heart in white or paper birch is a type of wetwood[2] (31, 68). One type of wetwood in white fir is called blackheart (146).

[1] Scientific names of commercial North American tree species mentioned in this report are listed in table 1 (conifers), page 5, and table 2 (hardwoods), page 6.

[2] R. W. Davidson, Colorado State University, personal communication to J. C. Ward.

Causes of Wetwood Formation

In general, wetwood is higher in moisture content than the adjacent normal heartwood. Reports of unusually high moisture content in heartwood may result from an investigator's inability to recognize wetwood. In comparison with sapwood, wetwood can be higher in moisture content (67, 79, 106, 117, 197) or lower or equal in moisture (20, 48, 121, 133, 203, 212, 215). Regardless of external appearance, wetwood differs from normal wood in physical and chemical properties and generally is more difficult to dry.

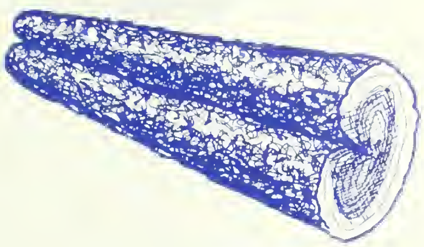
Wetwood in trees has been attributed to a number of causes: microbial (bacterial), nonmicrobial (injury), and normal age-growth formation. Associati relationships have been the basis of man evaluations of the causes of wetwood; actual tests to confirm cause-and-effect relationships have had little success.

Much of the research on wetwood has been directed toward investigating the association of bacterial infection and th occurrence of wetwood in trees (20, 25, 49, 60, 78, 79, 93, 106, 158, 167, 168, 190, 191, 202, 203, 206, 207, 214, 217, 219). Not all of these studies have fou bacteria to be associated with wetwood. Bacteria have frequently been isolated fr healthy sapwood and heartwood of living trees (12, 13, 40, 107, 144, 190, 214).

The concept that wetwood is the result o mixed population or invasion of more tha one species of bacteria could explain so of the differences in results. This concept would be analogous to the successions of organisms in the development wood decay and associated discolorations described by Shigo (171) and Shigo and Hillis (173). Strictly anaerobic bacter as well as facultative anaerobes have be isolated from wetwood (158, 174, 199, 20 203, 205, 206, 222). Laboratory techniq for isolating and culturing strictly anaerobic bacteria are different from th for aerobic and facultative anaerobes an fungi. This could explain why investigative results do not always agree about t relative importance of bacteria to formation of wetwood.

That wetwood formation or initiation may nonmicrobial in nature has been suggeste by some investigators (20, 45, 107, 144) and implied by others (12, 40, 190). Th investigations conclude that bacteria ar part of an indigenous microflora of norm wood, living in a viable but quiescent state until some change occurs in the wo to provide a favorable substrate (wetwoo for the bacterial growth. Bacteria iso-

ed from wetwood of poplar utilized
illary liquid from sapwood and heartwood
growth (190).



wood has been associated with physical, hanical, and biological injuries[3] (20, 186). Whether these injuries result in wood formation or initiate it has not n substantiated. Field observations e shown that the normal cylindrical form wetwood in white fir deviated radially longitudinally to regions of natural silvicultural injuries (observations by .Y. Pong). Similar deviations have been ed in conjunction with injuries arently caused by insect attacks[4] (78, 211) and stem cankers of dwarf mistletoe in true firs[5] (216). A fairly consistent association between wetwood and decay has been noted in eastern Oregon true firs[6] and other tree species (79). We have observed that internal heart rot in tree stems often has a peripheral ring of sound wetwood, whereas stems with wetwood do not necessarily have associated decay. There is some belief that wetwood may inhibit decay (93).

The inability to consistently associate wetwood with micro-organisms has led to the conclusion that wetwood in conifers is only a condition of excessive accumulation of moisture and not a symptom of disease (142, 165). There are opposing views on the source of the excessive moisture in wetwood. Some suggest direct entry of atmospheric moisture through stem openings, such as dead branch stubs (20); others believe water in wetwood has an internal origin from moisture sources in the root and stem (45, 78). In Japan the occurrence of wet heartwood is considered normal for some species of hardwoods and abnormal for conifers (220). Whether formation of wetwood is the result of a natural process of the tree or is bacterial in origin is discussed at length by Hartley, et al. (79). Until additional evidence is available, we will consider wetwood the manifestation of a syndrome of abnormal physiological events in the living tree and not a specific disease.

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[3] . Y. Pong. 1967. Preliminary study of le defects in true firs. Interim rep. A For. Serv. Pac. Southwest For. and ge Exp. Stn., 31 p. Berkeley, Calif. ublished report on file at Pac. thwest For. and Range Exp. Stn., land, Oreg.)

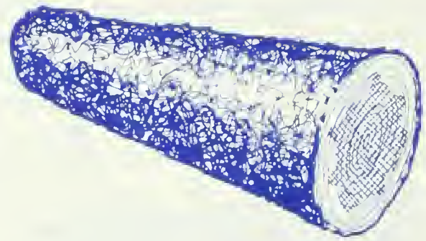
[4] Personal communication to W. Y. Pong m K. R. Shea, Assistant Director, ence and Education Administration, U.S. artment of Agriculture, Washington D.C., from W. W. Wilcox, Forest Products bratory, University of California, mond.

[5] J. R. Parmeter, Department of Plant Pathology, University of California, Berkeley, personal communication to W. Y. Pong.

[6] Field observations by P. E. Aho, Forestry Sciences Laboratory, Corvallis, Oreg.

Wetwood in Trees and Logs

Occurrence



Wetwood occurs in both conifers and hardwoods, but its frequency can vary by species, age, and growing conditions of trees. Occurrence of wetwood in the more important commercial timber species of North America is presented in table 1 for softwoods and table 2 for hardwoods. Each species is listed by its apparent susceptibility to wetwood formation. These classifications are derived from our observations, personal communications from colleagues, office reports, and the published literature. Tree species in which wetwood either has never been reported or is rarely observed are placed in class 1. Class 3 includes the most susceptible tree species or those that can be expected to develop wetwood either with age or under less than optimum growing conditions. The intermediate class 2 contains species in which wetwood is found in one locality and rarely, if at all, in another region.

For some species in both tables 1 and 2, the information is tentative; as additional field information becomes available a species may be moved from one class to another. Sufficient information exists to indicate that wetwood will probably develop in hemlocks, true firs, and cottonwoods from most regions. For species such as white pine, red oak, and maple, wetwood is found in many trees of one region and completely lacking in trees of another region. Thus, if the rating of a species in tables 1 and 2 is based on reports from a limited area of the total range of the species, then its status could be reversed when additional information is available.

Not all the tree species in class 3 a affected with wetwood to the same degr frequency. There are differences with genus; for example, white fir and gran are affected more than are noble fir a Pacific silver fir. From his studies white fir in northern California, Wilcox[7] found that all sample trees, including young ones, contained some wetwood. This appears to be the rule white fir in northern California, but some stands wetwood appears to be rare nonexistent.[8] The presence of wetwoo within the hardwood genus Populus appe to be the rule, but again there can be exceptions. Some investigators could n find eastern cottonwood trees that wer free of wetwood[9] (191, 222). For European white poplar (Populus alba L. the presence of wetwood is the rule in pistillate trees and the exception in staminate trees[10] (71).

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[7] W. W. Wilcox, Forest Products Laboratory, University of California, Richmond, personal communication to W. Pong.

[8] J. C. Ward, unpublished data on file U.S. Forest Products Laboratory, Madis Wis.

[9] J. B. Baker, Southern Forest Experim Station, New Orleans, La., personal communication to J. C. Ward.

[10] J. C. Ward and J. G. Zeikus, unpublished data on file at U.S. Fores Products Laboratory, Madison, Wis.

ıble 1--Occurrence of wetwood in commercially important conifers of the United States[1/]

Species	Frequency class[2/]		
	1 Occasional or none	2 Scattered prevalence	3 Generally prevalent
uglas-fir (Pseudotsuga menziesii (Mirb.) Franco)	+		
stern hemlock (Tsuga canadensis (L.) Carr.)			+
stern hemlock (Tsuga heterophylla (Raf.) Sarg.)			+
untain hemlock (Tsuga mertensiana (Bong.) Carr.)			+
ue fir:			
Balsam fir (Abies balsamea (L.) Mill.)			+
White fir (Abies concolor (Gord. & Glend.) Lindl. ex Hildebr.)			+
Grand fir (Abies grandis (Dougl.) ex D. Don) Lindl.)			+
Subalpine fir (Abies lasiocarpa (Hook.) Nutt.)			+
Pacific silver fir (Abies amabilis (Dougl.) ex Forbes)		+	
Noble fir (Abies procera Rehd.)		+	
California red fir (Abies magnifica A. Murr.)		+	
Shasta red fir (Abies magnifica var. shastensis Lemm.)		+	
ruce:			
White spruce (Picea glauca (Moench) Voss)	+		
Black spruce (Picea mariana (Mill.) B.S.P.)	+		
Red spruce (Picea rubens Sarg.)	+		
Engelmann spruce (Picea engelmannii Parry ex Engelm.)	+		
Sitka spruce (Picea sitchensis (Bong.) Carr.)	+		
ft pine:			
Eastern white pine (Pinus strobus L.)		+	
Western white pine (Pinus monticola Dougl. ex D. Don)		+	
Sugar pine (Pinus lambertiana Dougl.)		+	
rd pine:			
Jack pine (Pinus banksiana Lamb.)	+		
Lodgepole pine (Pinus contorta Dougl. ex Loud.)		+	
Red pine (Pinus resinosa Ait.)	+		
Ponderosa pine (Pinus ponderosa Dougl. ex Laws.)		+	
Shortleaf pine (Pinus echinata Mill.)	+		
Loblolly pine (Pinus taeda L.)	+		
Longleaf pine (Pinus palustris Mill.)	+		
Slash pine (Pinus elliottii Engelm. var. elliottii)	+		
Jeffrey pine (Pinus jeffreyi Grev. & Balf.	+		
stern larch (Larix occidentalis Nutt.)		+	
marack (Larix laricina (Du Roi) K. Koch)		+	
dwood (Sequoia sempervirens (D. Don) Endl.)		+	
ant sequoia (Sequoia dendron giganteum (Lindl.) Buchholz)	+		
ldcypress (Taxodium distichum (L.) Rich.)	+		
dar:			
ncense-cedar (Libocedrus decurrens Torr.)	+		
estern redcedar (Thuja plicata Donn ex D. Don)		+	
orthern white-cedar (Thuja occidentalis L.)	+		
laska-cedar (Chamaecyparis nootkatensis (D. Don) Spach)	+		
ort-Orford-cedar (Chamaecyparis lawsoniana (A. Murr.) Parl.)	+		
tlantic white-cedar (Chamaecyparis thyoides (L.) B.S.P.)	+		
astern redcedar (Juniperus virginiana L.)	+		
iper:			
lligator juniper (Juniperus deppeana Steud.)	+		
estern juniper (Juniperus occidentalis Hook.)	+		

[1/] rom field observations by authors augmented with personal communications; also from literature, p ticularly Hartley et al. (79) and Lutz (126).

[2/] requency class 1 includes tree species in which wetwood rarely, if ever, occurs and species in w ch wetwood has not been observed, reported, or recognized as wetwood. Class 2 includes species in w ch wetwood will develop on some sites and not on other sites, together with species that tend to d elop wetwood with increasing age on certain sites. Class 3 includes species very susceptible to f mation of wetwood on most sites and in young- as well as old-growth timber.

Table 2--Occurrence of wetwood in commercially important hardwoods of the United States[1/]

Species	Frequency class[2/] 1 Occasional or none	2 Scattered prevalence	3 Generall[y] prevalen[t]
Red oak group:			
Northern red oak (Quercus rubra L.)		+	
Black oak (Quercus velutina Lam.)		+	
Scarlet oak (Quercus coccinea Muenchh.)		+	
Pin oak (Quercus palustris Muenchh.)		+	
Water oak (Quercus nigra L.)		+	
Nuttall oak (Quercus nuttallii Palmer)	+		
Southern red oak (Quercus falcata Michx. var. falcata)	+		
Cherrybark oak (Quercus falcata var. pagodaefolia Ell.)		+	
Willow oak (Quercus phellos L.)	+		
Laurel oak (Quercus laurifolia Michx.)		+	
Shumard oak (Quercus shumardii Buckl. var. shumardii)	+		
California black oak (Quercus kelloggii Newb.)		+	
White oak group:			
White oak (Quercus alba L.)	+		
Bur oak (Quercus macrocarpa Michx.)	+		
Overcup oak (Quercus lyrata Walt.)		+	
Swamp white oak (Quercus bicolor Willd.)		+	
Chestnut oak (Quercus prinus L.)	+		
Swamp chestnut oak (Quercus michauxii Nutt.)	+		
Chinkapin oak (Quercus muehlenbergii Engelm.)	+		
Post oak (Quercus stellata Wangenh. var. stellata)		+	
Oregon white oak (Quercus garryana Dougl. ex Hook)		+	
California white oak (Quercus lobata Nee)		+	
Tanoak (Lithocarpus densiflorus (Hook. & Arn.) Rehd.)		+	
Hickory:			
Bitternut hickory (Carya cordiformis (Wangenh.) K. Koch)		+	
Water hickory (Carya aquatica (Michx. f.) Nutt.)		+	
Pecan (Carya illinoensis (Wangenh.) K. Koch)		+	
Shagbark hickory (Carya ovata (Mill.) K. Koch)	+		
Shellbark hickory (Carya laciniosa (Michx. f.) Loud.)	+		
Mockernut hickory (Carya tomentosa (Poir.) Nutt.)	+		
Pignut hickory (Carya glabra (Mill.) Sweet)	+		
Black walnut (Juglans nigra L.)		+	
Butternut (Juglans cinerea L.)	+		
Sweetgum (Liquidambar styraciflua L.)		+	
Maple:			
Sugar maple (Acer saccharum Marsh.)	+		
Silver maple (Acer saccharinum L.)	+		
Red maple (Acer rubrum L.)		+	
Black maple (Acer nigrum Michx. f.)	+		
Bigleaf maple (Acer macrophyllum Pursh)	+		
Black tupelo (Nyssa sylvatica Marsh.)		+	
Water tupelo (Nyssa aquatica L.)		+	
Yellow poplar (Liriodendron tulipifera L.)		+	
Magnolias (Magnolia L. spp.)	+		

ble 2--Continued

Species	Frequency class[2/]		
	1 Occasional or none	2 Scattered prevalence	3 Generally prevalent
h:			
White ash (*Fraxinus americana* L.)		+	
Green ash (*Fraxinus pennsylvanica* Marsh.)		+	
Black ash (*Fraxinus nigra* Marsh.)		+	
Oregon ash (*Fraxinus latifolia* Benth.)		+	
erican beech (*Fagus grandifolia* Ehrh.)		+	
plar and aspen:			
Eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.)			+
Plains cottonwood (*Populus sargentii* Dode)			+
Narrowleaf cottonwood (*Populus angustifolia* James)			+
Black cottonwood (*Populus trichocarpa* Torr. & Gray)			+
Fremont cottonwood (*Populus fremontii* Wats.)			+
Swamp cottonwood (*Populus heterophylla* L.)			+
Balsam poplar (*Populus balsamifera* L.)			+
Quaking aspen (*Populus tremuloides* Michx.)		+	
Largetooth aspen (*Populus grandidentata* Michx.)		+	
ack willow (*Salix nigra* Marsh.)			+
d alder (*Alnus rubra* Bong.)		+	
rch:			
Paper birch (*Betula papyrifera* Marsh.)		+	
Gray birch (*Betula populifolia* Marsh.)		+	
Yellow birch (*Betula alleghaniensis* Britton)		+	
River birch (*Betula nigra* L.)		+	
erican sycamore (*Platanus occidentalis* L.)			+
ack cherry (*Prunus serotina* Ehrh.)		+	
rthern catalpa (*Catalpa speciosa* Warder ex Engelm.)	+		
m:			
American elm (*Ulmus americana* L.)		+	
Slippery elm (*Ulmus rubra* Mühl.)		+	
Rock elm (*Ulmus thomasii* Sarg.)	+		
ckberry (*Celtis occidentalis* L.)	+		
garberry (*Celtis laevigata* Willd.)	+		
o buckeye (*Aesculus glabra* Willd.)	+		
low buckeye (*Aesculus octandra* Marsh.)	+		
rican basswood (*Tilia americana* L.)		+	
te basswood (*Tilia heterophylla* Vent.)	+		
ific madrone (*Arbutus menziesii* Pursh)		+	
d mulberry (*Morus rubra* L.)		+	
ck locust (*Robinia pseudoacacia* L.)	+		
ney locust (*Gleditsia triacanthos* L.)		+	
ter locust (*Gleditsia aquatica* Marsh.)		+	
ntucky coffeetree (*Gymnocladus dioicus* (L.) K. Koch)		+	

[1/] rom field observations by authors augmented with personal communications; also from literature, rticularly Hartley et al. (79) and Lutz (126).

[2/] requency class 1 includes tree species in which wetwood rarely, if ever, occurs and species in ch wetwood has not been observed, reported, or recognized as wetwood. Class 2 includes species in ch wetwood will develop on some sites and not on other sites, together with species that tend to elop wetwood with increasing age on certain sites. Class 3 includes species very susceptible to mation of wetwood on most sites and in young- as well as old-growth timber.

Even though considerable data may show that a species in class 1 is not susceptible to wetwood formation, it may be important to continue looking for exceptions. For example, we have rarely found wetwood in Douglas-fir and then it was limited in volume to small streaks or pockets. Nevertheless, one small stand of Douglas-fir timber in the Cascade Range of Oregon contained extensive wetwood in the logs, and the lumber was difficult to dry to a uniform moisture content.[11] In Washington, a Douglas-fir bridge timber which failed from ring shake was found to have contained extensive bacterial wetwood (see footnote 8).

Age has some influence on formation of wetwood. In general, there is less wetwood in young trees; some foresters think that the problem will be solved when the last old-growth timber is cut. In some species, such as cottonwood, aspen, elm, maple, and white fir, wetwood has been recorded in very young trees (see footnote 7) (79).

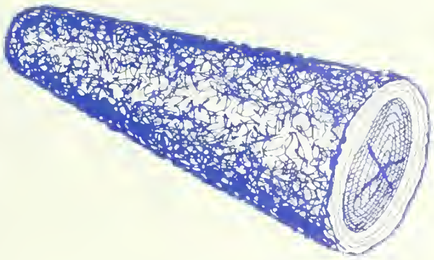
When wetwood is prevalent in young trees, site or cultural practices may be the major contributing factors. Field observations by the senior author indicate that site conditions may influence the incidence of wetwood in young-growth western hemlock. Wallin (197) observed a relation between wetwood formation in balsam poplar and soil type. Wetwood is most prevalent in the lower stems of western redcedar growing on wet, swampy sites (73, 89). These soil or site factors may favor increases in populations of micro-organisms associated with wetwood. Similarly, cultural practices could contribute to the establishment and growth of these micro-organisms in trees. Most cottonwood trees grown in plantations on good soils in the Mississippi delta develop wetwood within 2 years. This is apparently related to the planting of scions in moist soil (see footnote 9). Second-growth aspen in northern Minnesota contains more wetwoo than aspen from the original forest.[12] This may be due to the origin of the second-growth trees from sprouts and a different species composition of the second-growth stands favoring attacks b both micro-organisms and stem-boring insects. Eis (53) found that root graf in natural stands of Douglas-fir, weste hemlock, and western redcedar can be a major factor in the spread of decay org isms from stumps to neighboring trees. Root grafts may also be a factor in the initiation and spread of wetwood. Cole Streams (42) suggest that wetwood bacte are spread by slime-flux insects.

Types of Wetwood and Patterns Within the Tree

With few exceptions, formation of wetwo has been restricted to the heartwood an heartwood-sapwood transition zones of living trees. Essentially two types of wetwood can occur in the living tree: wetwood formed from the aging of normal sapwood nearest the heartwood or injure sapwood and wetwood developed in previo formed heartwood. The two types freque occur together and are difficult to distinguish.

[11] C. J. Kozlik, Department of Forest Products, Oregon State University, Corvallis, personal communication to J. C. Ward.

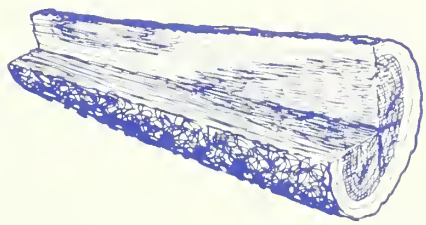
[12] E. M. Ballman, Chief Forester, Diamor International Corp., Cloquet, Minn., personal communication to J. C. Ward.



twood is generally not found in the outer pwood of living trees; reports to the ntrary indicate that such occurrence is sociated with insect attack, stem nkers, and wounds of various forms (79, ; also see footnotes 3, 5, and 7). In ese instances, the wetwood zone of the ntral core deviated radially and longi- dinally to the traumatized zone of the pwood. Knutson (106), however, was not ways able to relate wetwood in the pwood of aspen to visible wounds, but he nsidered wetwood to be generally a phe- menon of the sapwood. Takizawa et al. 86) found from the cytology of wetwood in e Japanese fir Todomatsu (*Abies chalinensis* Mast.) that wetwood was more mparable to sapwood than heartwood but it isted as streaks in the outer heartwood.

I is important that a distinction is made tween the wetwood or "sinker" stock .e., wood that will not float) formed in e standing tree and the "sinker wetwood" sulting from storage of logs in water. I pond-stored logs, the affected wood is inly the sapwood and the wood of the tral core exposed on the log ends. d-stored logs cease to float because of creased permeability from bacterial integration of pit membranes in the wood but not the heartwood (44, 50, 55, 6 72, 90, 95, 105, 119, 157, 180, 195, 2). In comparison, wetwood in standing es is confined more to the heartwood and registered lower permeability than the acent normal wood, particularly wood. The permeability of wetwood from es is discussed in the section on perties of wetwood.

Although the spatial distribution of wetwood in standing trees will vary by point of origin, duration of formation, and other such factors, there are essentially three general patterns. Most common is the conical pattern in the central core of the lower bole--the wetwood originates at injuries in the roots or at the root collar and tapers to an apex in the upper bole. This pattern has been found in true firs (45, 92, 147, 215), western hemlock (203), northern red oak (75, 202), eastern cottonwood (see footnote 9), and western larch (see footnote 8).



The second pattern consists of streaks or columns of wetwood which can be traced to injuries or to stubs of dead branches in the upper stem. The basal portion of these trees may be free of wetwood. Upper stem wetwood has been noted in trembling aspen (106), cricket-bat willow (*Salix alba* var. *calva* G. F. W. Mey.) (49), elm (33), eastern white pine (123), silver fir (*Abies alba* Mill) (20), California white fir, 13/ and eastern and western hemlock14/ (see footnote 11).

13/A. L. Shigo, Forestry Sciences Laboratory, Durham, N. H., personal communication to J. C. Ward.

14/ Field observations by the authors.

The third pattern appears when a tree contains both basal and upper stem wetwood formations that extend and coalesce into a single massive formation. This pattern was noted in Scots pine and Norway spruce (*Picea abies* (L.) Karst) by Lagerberg (117) who also was the first to describe the other patterns. It is not uncommon for aspen in Minnesota and Wisconsin (see footnote 8) and balsam fir (59) to have the combined wetwood pattern.

Wetwood Properties-- A Microbial Implication

Wetwood has distinctive physical and ch cal properties. These properties appe to result from microbial action on wood tissue in the living tree, but more comprehensive tests are needed to valid this relationship.

Odor

The odor of wetwood in the green condit differs from that of normal wood and is reminiscent of fermentation processes. This indicates an influence by anaerobic bacteria. Odors in wetwood ranging fror rancid to a fetid rumenlike odor have be traced to bacterial metabolism of woody components, particularly extractives anc hemicelluloses (1, 187, 222, 223). Usir potato mash media in the laboratory, the senior author (unpublished data) was abl to reproduce the rancid, fatty acid odor of wetwood with pure cultures of *Clostridium* spp. isolated from wetwood c cottonwood, red oak, and white fir. Ba et al. (20) found acetic acid, propionic acid, and n-butyric acid present in the wetwood of silver fir, but not in the sapwood. They believe these fatty acids indicate a high bacterial activity in wetwood.

Hydrogen Ion Concentration or

The prevailing belief is that wetwood ha a higher pH than normal wood. This can probably be traced to the publication, "Wetwood, Bacteria, and Increased pH in Trees," by Hartley et al. (79), who cite results indicating a higher pH in wetwoc of many hardwoods and conifers. They cautioned, however, that not all wetwood notably high in pH and that it is unsafe assume that all wood with high pH is wetwood or has been.

review of published data indicates that a omprehensive statement concerning the pH f wetwood cannot be made now. Reported pH alues are generally on the alkaline side or wetwood in hardwoods and on the acid ide for conifers, but there are exceptions etween tree species and even within single pecies and trees. In comparison with ormal sapwood and heartwood, wetwood of uropean aspen (Populus tremula L.) was ore acid (144), but wetwood in aspen from innesota can be either more acid or more lkaline (41, 67, 106). All wetwood in elm ested by Carter (33) was more alkaline han a slightly acidic normal wood. eliskar (167) found that wetwood in elm an be either acid or alkaline, whereas the etwood of Lombardy poplar (Populus nigra ar. italica Muenchh.) was consistently on he alkaline side. Wetwood in balsam poplar s slightly basic, the sapwood slightly cidic, and the heartwood essentially eutral (197). Red heart, a type of etwood in paper birch, is alkaline djacent to the acidic sapwood and turns cidic near the pith (31). Wetwood in onifers is more acid than the adjacent ormal wood for California white fir (212, 15), silver fir (20), and western hemlock 11). Another study of western hemlock eported that wetwood and normal heartwood ad a similar range in pH values from 4.1 o 5.5 (165). Any increases in the pH of etwood from conifers are small (79).

Until additional studies are made we can only speculate on the causes for differences in pH between wetwood and normal wood and between wetwood in individual trees and species. Microbial populations in trees are possible causative agents, but they must be considered in conjunction with site and chemistry of the trees. Seliskar (167) noted that elms on poor sites had alkaline wetwood, whereas wetwood from trees on good sites was acidic. From laboratory test cultures, Carter (33) observed that the elm wetwood bacterium, Erwinia nimipressuralis, will turn a nutrient broth containing a sugar strongly acid; but growth on nutrient broth alone will result in an alkaline pH. Toole (191) reports that wetwood in eastern cottonwood growing along the Mississippi River between Vicksburg, Mississippi, and Memphis, Tennessee, is neutral to alkaline, and the sapwood is slightly acidic. The senior author found similar acidic pH values for sapwood of cottonwood growing along the Mississippi River in Wisconsin, but the wetwood had either higher or lower pH values than sapwood. The composition of the microbial population in wetwood varies with either acid or alkaline pH conditions for eastern cottonwood (222) and California white fir (see footnote 10). Whether differences in pH are the cause or the result of differences in microbial populations has not been determined.

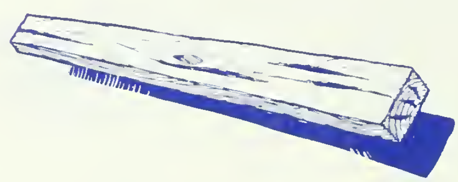
Anaerobiosis

Results from analysis of gas samples from wetwood in hardwood trees range from near anaerobic conditions in elm (33) and black cottonwood (93) to strictly anaerobic with no oxygen present in eastern cottonwood (222). Carbon dioxide, nitrogen, and oxygen are the major gaseous components of normal wood, but oxygen was absent or in very reduced amounts in the wetwood studied, indicating that any bacteria present must be either facultative or obligate anaerobes. During the summer growing season, high positive gas pressures have been recorded in wetwood of standing hardwood trees, and these pressures are attributed to bacterial metabolism (33, 79, 191, 221, 222). Trunk gases contributing to the positive pressures in wetwood are carbon dioxide, hydrogen, methane, nitrogen, and hydrogen sulfide. Zeikus and Ward (222) established that the methane gas is produced by an autotropic anaerobe which is a secondary invader and not common to all wetwood populations even within the same host species. This methanogen, subsequently characterized and named Methanobacterium arbophilicum by Zeikus and Henning (221), is also found in soil and water. It can only grow under strictly anaerobic conditions and in the living tree only in wetwood where it metabolizes hydrogen and carbon dioxide produced by Clostridium and other anaerobic bacteria. These other bacteria must, in turn, derive nourishment from the woody tissue.

Van der Kamp et al. (93) consider wetwood with its near anaerobic conditions a perfectly natural phenomenon that imparts resistance to decay to the inner wood of black cottonwood trees.

Strength Properties

There are conflicting reports in the literature concerning the relative stre properties of wetwood compared with nor sapwood and heartwood. Some investigat found wetwood weaker than normal wood; others report wetwood to be equal and e greater in strength. We have found fro observations made in conjunction with various tests on sawing, machining, dry and mechanical strength properties that wetwood is often weaker than normal woo bonding strength of the compound middle lamella between wood cells. The second wall of wetwood cells does not appear t weaker than that of normal wood with similar specific gravity. Conflicting reports on the comparative strength properties of wetwood can usually be resolved by normalizing test results fo sample moisture content, sample size an methods of preparation, and specific gravity of samples.



Results from mechanical tests showing wetwood of hardwoods to be weaker than normal wood were all derived from the testing of green wood (40, 41, 80, 106, 133); furthermore, the wetwood was usua lower in specific gravity than adjacent normal wood. It is important that test specimens be cut from dried wetwood rat than from green wetwood and then dried; during drying, deep surface checks, rin failure, and internal honeycomb checks much more likely to develop in wetwood in normal wood. Lagerberg (117) and Thunell (189) found that Scots pine wet was weaker in bending, compression, and impact strength properties than were no sapwood and heartwood. They attributed

ɔwer strength of wetwood to weakness of ıe middle lamellae and seasoning checks in ıe air-dried test specimens. Test speci- ɛns cut from green wetwood will not have ɛasoning checks, but green wetwood is more ikely to have tissue with weaker bonds ɛtween cells than samples selectively cut om the defect-free portion of dried ɛtwood blanks or boards. Toughness :rength of green wetwood samples from ıite fir (212, 215) and from American and ippery elm (167) was not significantly ɔwer than normal wood when differences in ɛecific gravity were accounted for.

If specimens used in mechanical testing can be prepared from dry, defect-free wetwood, then strength differences between wetwood and normal wood diminish. Stojanov and Enthev (181) found that air-dried specimens from wetwood of silver fir were equal in static bending strength and stronger in compression strength than was normal wood. Table 3 shows that small test beams of wetwood cut from kiln dried boards of California white fir are as strong in static bending properties as is normal wood. Differences between strengths of wetwood and normal wood were related to differences in specific gravity; however, during the preparation of the test specimens, many wetwood samples developed shelling failures and could not be tested. Table 3 also shows that sugar pine wetwood was weaker than normal wood even though higher in specific gravity.

ıble 3--Comparison of specific gravity and mechanical strength properties of normal wood and wetwood (inker heartwood) from California white fir and sugar pine[1/]

Sɛcies and wɔd type	Specific gravity oven dry weight, based on volume at test		Static bending strength properties[2/]					
			Modulus of rupture		Modulus of elasticity		Stress at proportional limit	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
	12-percent moisture content		Pounds per square inch		Thousand pounds per square inch		Pounds per square inch	
Wıte fir:								
Sapwood	0.353	0.012	9,601	787	1,313	90	5,968	611
Heartwood	.343	.018	9,054	870	1,355	97	5,578	628
Wetwood	.429	.072	11,329	2,347	1,649	338	5,997	1,253
Sıar pine:								
Sapwood	.266	.016	5,643	587	708	106	3,588	430
Heartwood	.271	.024	6,049	702	686	87	3,883	491
Wetwood	.281	.020	5,529	606	674	68	3,041	369

[1/] est samples from kiln-dried lumber. Unpublished data from J. C. Ward, U.S. Forest Products Laboratory, Mıison, Wis.

[2/] trength values at 12-percent moisture content from test specimens measuring 1 by 1 inch in cross-sɛtion and 16 inches along the grain (bending test over a 14-inch span).

The intrinsic weakness of wetwood in cell-to-cell bonding strength appears to be related to the production of pectin-degrading enzymes by bacteria, especially the obligate anaerobe *Clostridium*. These enzymes degrade the pectic substances in the compound middle lamella that holds together the wood cells. Wong and Preece (219) observed degradation of the middle lamellae of cricket-bat willow by the facultative anaerobe *Erwinia salicis* which also produces pectolytic enzymes. Soluble sugars could not be detected in the wetwood of *Abies alba*, so Bauch et al. (20) assumed that pectinaceous compounds and hemicelluloses serve as substrates for wetwood bacteria. Bacteria isolated from wetwood have not been found capable of degrading lignin and cellulose or the secondary cell wall under laboratory conditions (214, 217). Furthermore, microscopic examination of wetwood indicates that secondary walls are not visibly degraded as are the walls of wood decayed by fungi or attacked by wood-destroying bacteria (79, 106, 107, 117, 122, 130, 158, 164, 213). Hillis et al. (83) consider wetwood bacteria responsible for shake in trees.

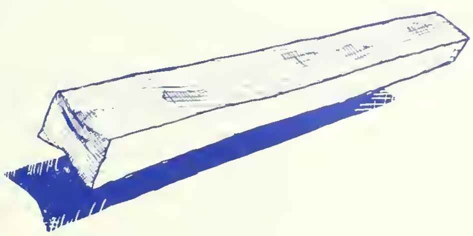
Sometimes a strong, pectin-degrading bacterium will be absent from the microbial population in wetwood and shake, deep checks, and honeycomb will not appear in the wood. For example, when American elm wetwood was without *Clostridium* in its microbial population, the wood did not develop deep surface checks, honeycomb, or ring failure during kiln drying (24). American elm with wetwood infected by *Clostridium* is highly susceptible to ring failure and shelling when subjected to drying and machining stresses and is referred to as "onion elm" in the lumber trade.

Ordinarily, sapwood will not develop ri
shake and honeycomb, but these defects
occur if sapwood is submerged and infec
by bacteria that produce pectolytic enz
(180). Salamon (160) found that honeyc
and shake occurred in dried sapwood boa
from dead lodgepole pine and Engelmann
spruce trees salvaged from flooded area
He observed heavy concentrations of
bacteria in this sapwood under the elec
microscope and considered bacteria resp
sible for the defects. Boards from
sprinkled or water-stored Scots pine an
Norway spruce logs were also found by
Boutelje and Ihlstedt (26) to be more
liable to checking than boards from new
felled trees. A wide variety of bacter
including anaerobic pectin-degrading
Clostridium spp., were isolated from
sapwood of water-stored Scots pine by
Karnop (95) but not from the heartwood.

Permeability

Wetwood has long been considered to hav
low permeability because it is extremel
slow to dry and wet pockets are often
present in dry lumber (79). Several
studies have correlated slow drying of
lumber with restricted flow of liquids
gases through small cores of wetwood fr
aspen (98, 106), western hemlock (111,
121), and western redcedar (188). On t
other hand, the absorptive capacity of
wetwood can be greater than that of no
wood. In the green condition, white f
wetwood is slow drying, but it will ab
more oil than normal wood does after dr
(9, 215, 217). Air-dried wetwood from
Scots pine has greater water absorptio
capacity than normal wood and the capi
rise of water is much more rapid, yet t
lumber will contain wet pockets with
moisture content as high as 100 percen
(117). The moisture-holding capacity
elm wetwood does not exceed that of no
wood (167), but elm lumber with wetwoo
does not dry abnormally slowly either

For a better understanding of the total concept of permeability for wetwood, studies should be designed to evaluate the relative contributions of wetwood extractive, pit aspiration, tyloses, and bacterial metabolism. Wetwood can have concentrations of extractives that not only may block cell lumens and pits, but can also have greater osmotic pressures than normal wood (6, 20, 45, 83, 106, 112, 117, 136, 139, 165, 169). Reduced permeability of wetwood has been associated with aspiration of bordered pits in softwoods (111, 121, 203) and tyloses in hardwoods (98, 106, 205). Bacteria have produced slime or extracellular polysaccharides in the wetwood of both conifers and hardwoods (158, 203, 205). Bacterial slime can contribute to blockage of cells and increased osmotic pressure.



In contrast to wetwood, the permeability of water-stored logs is increased, rather than decreased, by bacteria. Porosity of water-stored wood is increased by bacterial degradation and destruction of pit membranes and thin-walled parenchyma cells, especially in the rays (21, 26, 50, 55, 63, 72, 90, 94, 95, 105, 119, 157, 195, 208). To a limited degree, cell walls in water-stored sapwood may be pitted and corroded (44, 69, 70, 72, 96, 119), suggesting that bacteria may be attacking the wood under aerobic rather than anaerobic conditions. Karnop (94) found that the anaerobic Clostridium omelianski can attack unlignified cellulose in the sapwood of water-stored pine, but this activity is reduced with low water temperature and acidic conditions.

Chemical Brown Stain Precursors

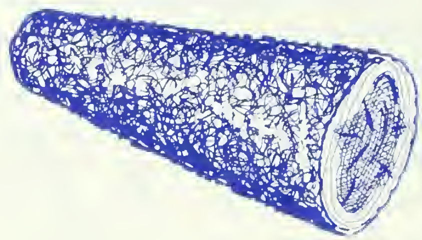
Dark discolorations or chemical brown stains frequently develop on the surface of wetwood which, after being removed from the anaerobic atmosphere of the tree, is exposed to aerobic or oxidative conditions. The intensity of these chemicals or oxidative brown stains varies with wood drying conditions, tree species, and individual trees. Wetwood has been associated with dark discolorations in both hardwoods and softwoods (79), particularly in these species: aspen (79, 84, 106, 133), white popular (71), eastern white pine (35), western redcedar (136), redwood (5), western hemlock (18, 165), "Sugi" (*Cryptomeria japonica* (L.F.) D. Don) (66), paper birch and sugar maple (79), and cricket-bat willow (47, 209, 219).

Bacterial degradation of the normal wood sugars and polyphenols may cause wetwood to develop dark oxidation stains when dried. Chemical brown stain has been attributed to the bacterial attack on extractives in sugar pine (182), western hemlock (61), and Pacific silver fir (19). The Forest Products Laboratory's (FPL) investigations (see footnote 8) found that the formation of chemical brown stain in freshly sawed green lumber from California white fir, sugar pine, eastern white pine, western hemlock, aspen, and cottonwood is associated with and confined to the wetwood zones of these trees. This stain, however, did not develop uniformly in all wetwood of these species; variations in composition of bacterial populations appear to be important. FPL data suggest that the presence of phenyloxidizing bacteria similar to those described by Greaves (70) is required before very dark chemical brown stain develops in wetwood.

Timber Utilization and Wood Processing Proble

Chemical brown stain in wetwood is identical to the so-called sour log brown stain that develops on the surface of softwood lumber sawn from logs stored under water or in moist, shaded log decks. Millett (141) observed that brown stain precursors can be present in sugar pine trees, or the precursors can form by enzymatic or hydrolytic degradation in stored logs. Both types of brown stain may have similar biochemical origins. Bacteria are considered factors in the formation of sour log brown stain on sapwood of western pines (55, 182, 183). Knuth (104) discovered that chemical brown stain, but not decay, will develop on the surface of wood samples submerged in liquid cultures of bacteria. Formation of stain was enhanced by autoclaving the wood before inoculation, and aerobic conditions were necessary for final development of stain. Evans and Halvorson (61) studied the chemistry of brown stain in water-stored sapwood and wetwood of western hemlock. From their research, they were able to postulate that bacterial enzymes (probably polyphenol oxidases) condense monomeric leucoanthocyanins to water soluble polymers. These polymers migrate to the wood surface during drying and on exposure to the atmosphere undergo oxidative condensation to dark brown polymers.

The presence of wetwood can cause substantial economic losses when the affec timber is converted into logs and end-u products. Since wetwood is usually lim to inner sapwood and heartwood, it seem ingly is not detrimental to growth of trees. In trees where wetwood radiates into the outer sapwood from the central core because of insect attack and other stem injuries, the function of sapwood be impaired. To what extent this may affect the growth of the tree has not b investigated.

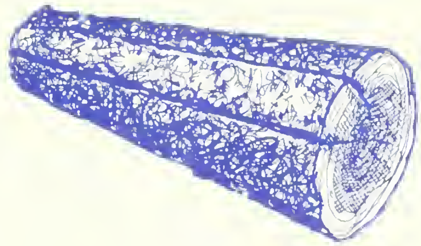


Shake and Frost Cracks

The weaker bonding between the cells of wetwood can result in radial and tangen growth ring separations when the affect trees are subjected to stresses from wi growth, and freezing. These separation known as shake (radial and ring) and sometimes spangles, are internal defect the trunk that often go undetected when tree appears vigorous and healthy. Sha can make boards with otherwise sound an clear wood, worthless for structural an factory grade lumber. The construction industry is the largest wood-using industry, and the losses in available construction grade lumber resulting fro shake in both trees and boards are considerable.

Many logs, both hardwood and conifer, are excluded from the most valuable log grades for lumber and veneer only because they contain shake (81, 117, 124, 125, 126, 127, 128). Shake in western hemlock logs from Alaska has caused staggering losses in the volume of wood intended for export to Japan.[15] An association between shake and wetwood has been proposed by many investigators (31, 33, 37, 79, 83, 96, 110, 111, 117, 202, 203, 204). Even though wetwood is present in conjunction with much of the shake observed in trees and logs, the actual formation of shake is a complex process involving other factors, such as tree growth stresses, stem injuries, and anomalous wood tissue (38, 83, 91, 113, 114, 115, 124, 129, 130, 140, 172, 173).

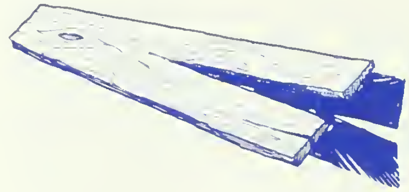
[15] R. O. Woodfin, Pacific Northwest Forest and Range Experiment Station, Portland, Oreg., personal communication to J. C. Ward.



Frost cracks on the outer stem surface appear to be an extension of shake from within the bole; they result not only in loss of usable wood volume but also in a reduced yield of high quality lumber or veneer from the logs. Wood from trees with frost cracks is likely to contain wetwood (see footnote 3) (46, 79, 88, 117). In European poplar plantations, frost crack is a common and serious defect consistently associated with bacterial wetwood in affected trees (57, 62, 82). Surveys of defect in western conifers do not indicate a close relationship between frost cracks and fungal decay (27, 65), yet frost cracks certainly offer a favorable infection court for decay fungi. Aho (2) found that less than 6 percent of the frost cracks in grand fir from Oregon and Washington were infected by fungi, and decay losses were small. He did find that all grand fir trees with frost cracks invariably had wetwood, and 46.7 percent of all trees 11.0 inches or more in diameter contained frost cracks.[16] From an extensive review of the literature, Schirp (163) found that the association of frost cracks with wetwood in tree stems dated back to 1765.

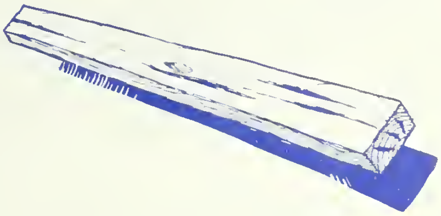
[16] P. E. Aho, Forestry Sciences Laboratory, Corvallis, Oreg., unpublished data.

Rapidly freezing air temperatures are also necessary for formation of frost cracks. In Macedonia, frost cracks developed in the stems of poplars (*Populus* x *euramericana* (Dode) Guinier) growing in an area with a continental climate (warm summer temperatures and cold oscillating winter temperatures), but not a single stem crack was observed on trees growing in an area with a Mediterranean climate (mild winters and hot summers) (74). Robert Hartig (77), the "father" of forest pathology, observed frost cracks to be most abundant on the northeast side of trees where sudden and large drops in temperature often occurred in winter. He also noted radial and peripheral cracks in the interior of old oaks; these cracks did not extend outside the stem, and he was uncertain whether they were due to frost. A survey of damage from frost cracks on walnut (*Juglans regia* L.) growing in the Ukraine showed that the number of stems affected ranged from 1.1 to 83.4 percent in stands on south slopes with fairly moist soils (185). White fir stands of the Sierra Nevada in California have two to three times more frost cracks in trees on the east slope with greater drops in temperature than on the milder west slope (196). Freezing of redwood boards results in breakage of heartwood with wetwood but not with normal heartwood below 150-percent moisture content (58).



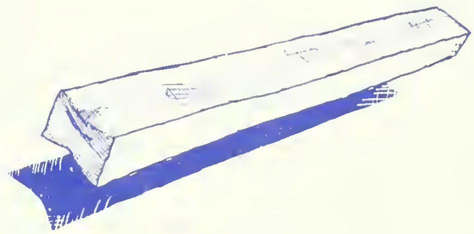
Losses in product volume and value associated with shake and frost cracks are especially important because these defect are most prevalent in the lower two logs trees and, in many instances, are spirale (see footnote 3) (163, 196). In the true firs, for example, these logs have the potential for producing not only the highest quality boards but also nearly ha the total lumber volume of the tree (215). It is in these logs that reducing wetwood related losses has its greatest potential, both in volume and value (147). The occurrence of combinations of shake, fros crack, and spiral grain in white spruce timber growing in northern Alberta seriously affected the yield of 1- and 2-inch dimension lumber (131). Shake caused 7 t 12 percent of the lumber output per tree be graded utility or lower. Degrade was higher, 15 to 22 percent, when frost crac were present; and trees with both frost cracks and spiral grain suffered the highest grade losses--23 to 26 percent.

Checking and Collapse



The unexpected occurrence of checking and collapse in lumber and veneer during drying can be attributed to the same weakening of the compound middle lamella that predisposes the wood to shake and formation of frost cracks in trees. In wetwood, drying checks can develop in both a radial and a tangential direction. Radial checks may be deep surface checks, internal ruptures called honeycomb, or bottleneck checks--deep surface checks that develop into a honeycomb. Tangential checks known as ring failure appear to be an incipient form of ring shake that starts in the tree; these checks do not actually rupture until subjected to shrinkage stresses (202). A description by Kutsche and Ethington (116) of various shelling failures during the machining of wood suggests that some failures may be related to wetwood and may possibly be an incipient form of ring shake. Collapse is essentially a collective internal failure of cell walls resulting in depressions on the surface of the dried board or veneer which cannot always be removed with surfacing. Figures and 2 show examples of honeycomb, ring ailure, and collapse that developed in etwood during drying. Deep surface checks re present in some pieces but are not isible because they close up toward the nd of drying when the surface is below 5-percent moisture content (MC) while the ore is still above 30-percent MC.

The dry kiln operation is often blamed for shake in dried lumber. Results from investigations with softwood dimension lumber reveal, however, that much of the observed shake was initiated in the tree and only became apparent after drying (37, 87, 140, 203). Shake in western hemlock lumber has been associated more with wetwood than with drying conditions (111, 203).



Green lumber with wetwood is more likely to develop collapse during the early stages of drying than lumber with normal sapwood and heartwood. Collapse can be expected in wetwood when the bonding strength between cells has been weakened and the rate of internal moisture loss through cell cavities is restricted. A generally held theory is that collapse can develop only in cell cavities that are completely saturated with water (142), but Kemp (98) was able to induce collapse in wetwood cells of aspen that were not completely saturated. He was also able to relate collapse to portions of the board with the lowest rates of moisture loss. Honeycomb and ring failure are often associated with collapse in wetwood. Reconditioning of collapsed lumber by steaming is possible when internal ruptures are not present (108).

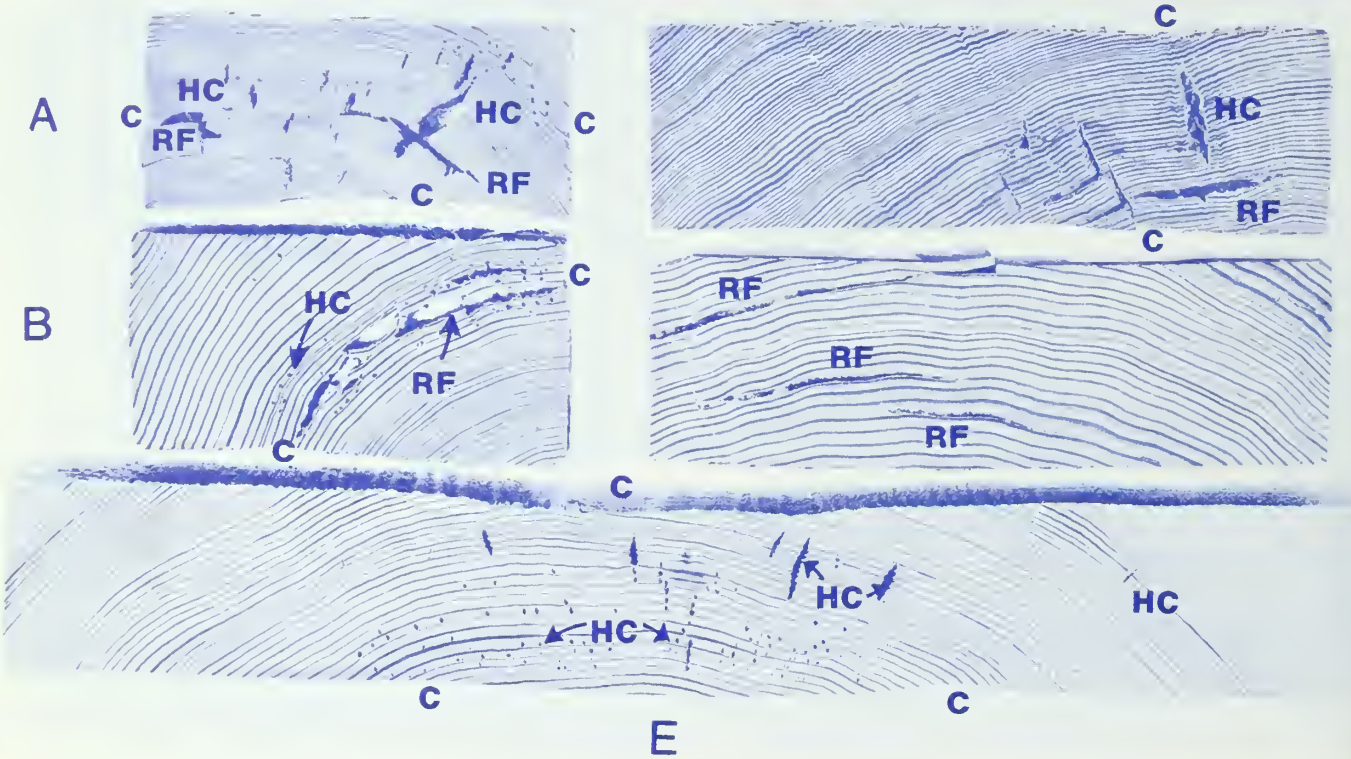


Figure 1.--Cross-cut sections from softwood boards with wetwood that developed collapse (C), honeycomb (HC), and ring failure (RF) in drying: **A**, *old-growth eastern hemlock;* **B**, *young-growth eastern hemlock;* **C**, *old-growth western hemlock;* **D**, *young-growth western hemlock;* **E**, *California white fir.*

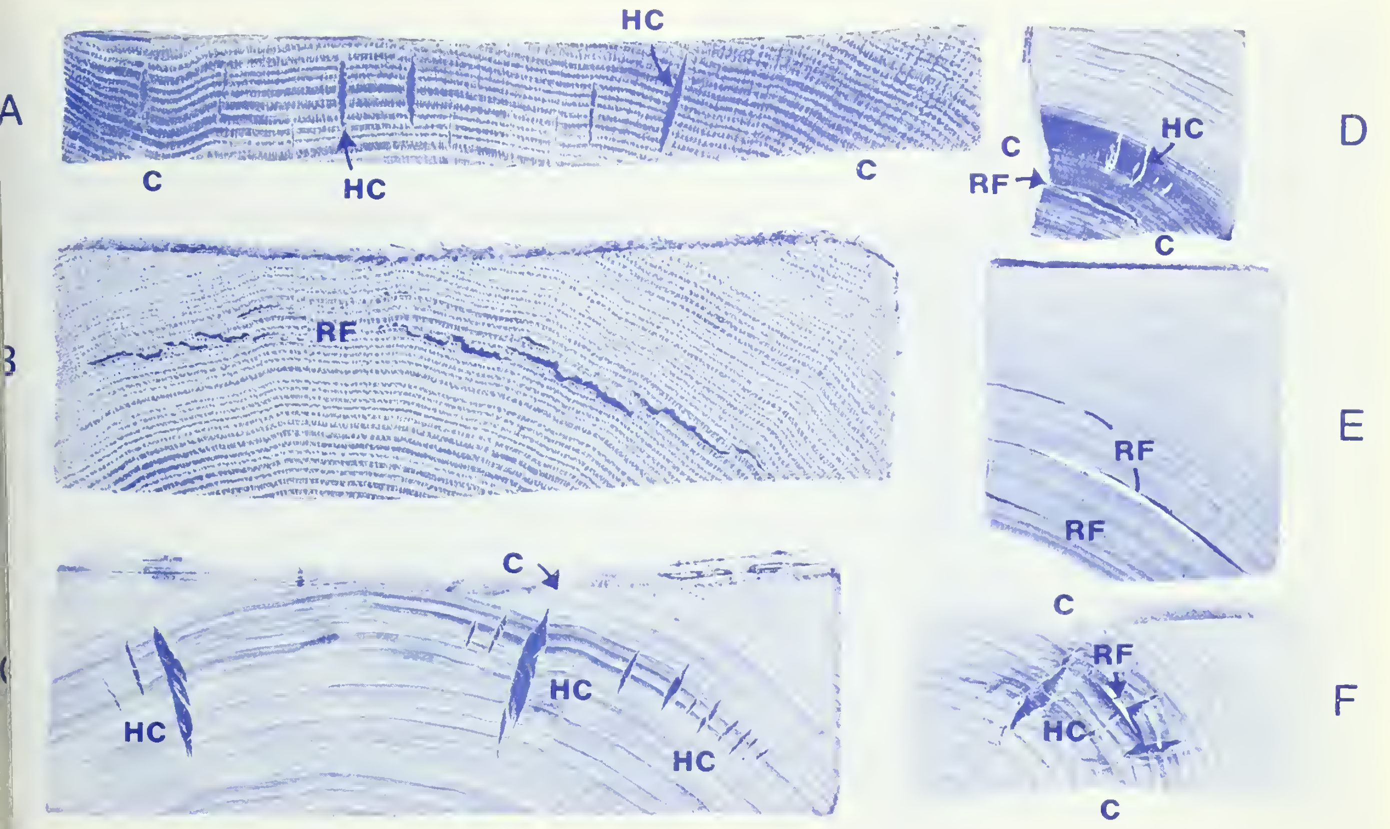
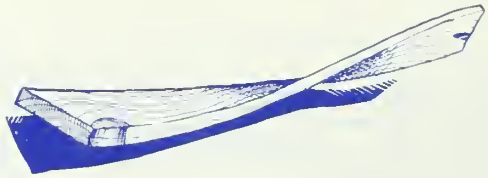


Figure 2.--Cross-cut sections from hardwood boards with wetwood that developed collapse (C), honeycomb (HC), and ring failure (RF) in drying: **A** and **B**, northern red oak; **C**, eastern cottonwood; **D**, red maple; **E**, American sycamore; **F**, largetooth aspen.

Two major sources of stress considered responsible for collapse during drying are liquid water tension produced by capillary forces in the cell which can be very high with rapid drying and compression stress perpendicular to the grain caused by a sharp moisture content gradient across the board (108, 142, 151). Little information is available on the comparative susceptibility of wetwood and normal wood to collapse. Kemp (98) found that aspen heartwood, artificially saturated with water, will collapse but only at a higher temperature than that required to first initiate collapse in wetwood. High drying temperatures can plasticize wood and make it less able to withstand the stresses associated with collapse (108). Thin-walled cells in the newly formed earlywood of outer sapwood have collapsed when the living tree is subjected to extreme moisture stress (198). Results from drying tests at the Forest Products Laboratory (see footnote 8) indicate that wetwood is susceptible to collapse under kiln-drying temperatures less than 212°F, but normal wood is not.

Collapse, honeycomb, and ring failure are costly defects associated with the drying of wetwood from white fir[17/] (145), western hemlock (100), redwood (138), western redcedar (51, 73, 188), aspen (41, 98, 133, 134), and west coast hardwoods (176)--particularly Pacific madrone (30), tanoak (154), and California black oak (205). The plugging of cell cavities with tyloses increases the tendency of wetwood to collapse in such hardwoods as aspen (98), overcup oak (126), California black oak (205), and red gum (151).

[17/] B. G. Anderson. Study of change in grade and footage loss in kiln dried white fir lumber from the green chain to the car. Report presented at the meeting of Eastern Oregon-Southern Idaho Dry Kiln Club, La Grande, Oreg., Nov. 19, 1954. 4 p. Oregon Forest Products Laboratory, Corvallis, Oreg.



The severity of honeycomb and collapse in wetwood usually increases with an increase in temperatures during the early and middl[e] stages of drying. Temperatures at which these defects begin to form in wetwood apparently vary with tree species, site conditions, and types of wetwood. When green lumber is kiln dried, honeycomb in the wetwood of California black oak and northern red oak can be minimized by lower initial dry bulb temperatures (202, 205). Wetwood in southern bottom-land oaks, however, honeycomb and collapse under the mildest kiln schedules; this lumber must initially be dried in the open air or dried in kilns at low temperatures to at least 25 percent MC before it can be kiln dried.[18/] Collapse in aspen wetwood can be reduced by using mild kiln conditions in the early stages of drying (98). Western redcedar lumber containing a particularly dark heavy type of wetwood will sometimes collapse after only 1 day o[f] air drying.[19/] With high temperature kiln schedules (temperature of 212°F or higher) most wetwood will honeycomb or collapse, but usually adjacent normal wood will not[20/] (36, 132, 134, 159).

[18/] Don Cuppett, Northeastern Forest Experiment Station, Princeton, W. Va., personal communication to J. C. Ward.

[19/] Jack McChesney, Louisiana Pacific Corp., Dillard, Oreg., personal communication to J. C. Ward.

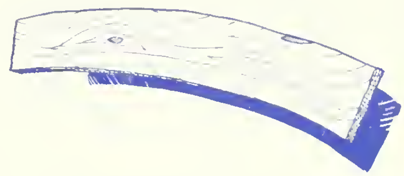
[20/] Unpublished data from drying studies; on file at U.S. Forest Products Laboratory Madison, Wis.

oneycomb and ring failure are major efects associated with kiln drying of oak, ur most important hardwood lumber pecies. Annual wood losses from drying efects associated with wetwood in oak actory grade lumber produced in the astern United States are estimated to be t least 3 percent. It is not unusual, owever, for 10 to 25 percent or even half he lumber charges from individual kilns o be lost because of honeycomb and ring ailure.

PL studies on kiln drying northern red oak lmber, green from the saw, showed 8- to -percent losses in volume from honeycomb d ring failure in wetwood (201). Mone-ry losses ranged from $34.28 to $139.42 r thousand board feet of rough dry lmber. Three studies of kiln drying Clifornia black oak (205) at a commercial ill showed losses from defects in wetwood t be 7 to 48 percent of the total volume o Number 1 Common and Better lumber. Ttal monetary loss in rough, dry lumber fr the three studies was over $9,000. Tis can explain why one large Los Angeles lmber company fills a standing monthly oder for one-half-million board feet of 44-inch kiln-dried oak lumber with oak iported from the Eastern United States.

Sith (180) estimates that, for British Clumbia, the development of honeycomb and rng shake in softwood studs with bacteri-aly infected wood will result in a reduc-ton in grade of $7 per thousand board fet. We can calculate from the average grade prices in "Random Lengths" (150) that dying defects associated with wetwood can case grade losses of $38 to $40 per thou-sad board feet for hem-fir dimension lmber.

Slow Drying Rates and Uneven Moisture Content



The wetwood of many species has low permeability and requires much longer drying times than normal wood to reach a desired moisture content. Even when wetwood boards reach the desired average MC, there is an uneven distribution of moisture where the shell is very dry but the core contains wet pockets or streaks that are still above the fiber saturation point. Sometimes after supposedly dry wetwood lumber is surfaced, the internal wet pockets dry and collapse, resulting in degrade of the lumber (134). Wet pockets can be a problem when dried wetwood from aspen and hemlock are used for core stock in the manufacture of doors and panels. Although these wet pockets may be pencil thin, they will build up enough steam pressure during electronic gluing opera-tions to explode and shatter the surface of the pieces.21/ Internal wet pockets in kiln-dried western hemlock causes erroneous determinations of MC when electronic meters are used (109).

21/ Elmer Cermak, Algoma Hardwoods, Inc., Algoma, Wis., personal communication to J. C. Ward.

A serious economic problem can result from the presence of impermeable wetwood in softwood dimension lumber for construction purposes. The same problem applies to aspen and poplar studs and light framing lumber graded under softwood rules. To meet moisture specifications for kiln-dried lumber softwood dimension lumber must be dried to at least 19-percent MC; the desirable range is 12 to 16 percent. Boards with wetwood may require 50 percent or more time in the dry kiln to reach 19-percent MC as do boards with sapwood and heartwood. When the volume of boards exceeding the 19-percent MC specification is greater than 5 percent, a kiln charge or shipment of kiln-dried lumber is considered to be in noncompliance with specifications for moisture[22/] (28, 178, 210, 218).

Slow drying of construction lumber containing wetwood can be expected for these softwood species: redwood (103, 138, 151), true firs (101, 103, 145, 151; also see footnote 17); western hemlock (29, 103, 110, 151), western redcedar (29, 103, 151, 159), and white pines (151). Hardwood species with impermeable wetwood and slow drying rates are: aspen (36, 86, 133, 200), red gum (151), and water and swamp tupelo (137). Redwood with heavy sinker heart is especially difficult to dry (138), and 1-inch-thick boards require 146 days of air drying to reach 20 percent MC (52). In contrast, 2-inch-thick redwood with light and medium heartwood can be air dried to 19-percent MC in 74 days (8). Arganbright and Dost (7) found that development of chemical brown stain decreases the drying rate of sugar pine and, at the end of drying, retards moisture movement back into the board surface during conditioning treatment.

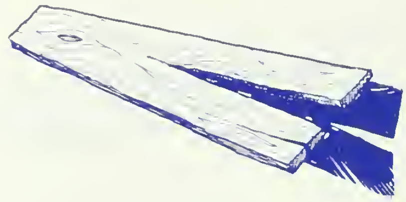


Table 4 shows that the slow drying rates of wetwood vary with tree species. Wetwood from aspen and the conifers is much less permeable than normal wood, whereas wetwood from cottonwood, elm, and oak takes only slightly longer to dry than normal wood. The effect of wetwood on reducing drying rates tends to decrease as thickness of boards decreases. For some species, the time required to dry veneer containing wetwood and veneer containing sapwood differs little for a given MC; but for species such as red gum, true firs, hemlock, larch, and redwood, there are decided differences (126). A comparison of drying times for green veneer from balsam fir and white fir (table 5) indicates that wetwood has an adverse effect on drying rates for even thin material.

Where wetwood boards occur in kiln charges of softwood and aspen dimension lumber, the processor is confronted with five possible alternatives; each may result in losses of wood and energy and in higher manufacturing costs.

1. The kiln residence time can be extended until the wet test boards reach the required 19-percent MC. This can cause overdrying of nonwetwood stock (i.e., below 11-percent MC), which is then subject to planer splits and costly degrade in subsequent machining operations (100, 101, 103, 110, 145, 218; also see footnotes 17 and 22).

22/G. Reinking. 1971. Kiln drying lumber to the moisture provisions of the new lumber standards. Forest Products Research Society News Digest File J-1.1, 2 p. Madison, Wis.

able 4--Drying times for green wetwood boards compared with drying times for boards containing normal wood[1]

pecies	Source of data	Board specifications: Thickness	Board specifications: Dried moisture content	Initial kiln temperatures[2]: DB	Initial kiln temperatures[2]: WB	Wetwood: Green moisture content	Wetwood: Drying time	Sapwood: Green moisture content	Sapwood: Drying time	Heartwood: Green moisture content	Heartwood: Drying time
		Inches	Percent	- - °F - -		Percent	Hours	Percent	Hours	Percent	Hours
oftwoods:											
Western hemlock	Ward and Kozlik (203)	1-34	15	180	176	150	139	156	82	54	59
Western hemlock	Kozlik et al. (111)	3/4	10	100	69	153	170	--	--	66.1	90
Eastern hemlock	J. C. Ward3/	1-3/4	15	180	170	148	185	137	95	75	96
White fir	Smith and Dittman (177)	1-7/8	20	160	145	193	158	145	84	57	42
White fir	Smith and Dittman (177)	1-7/8	4/15	160	145	193	4/195	145	4/97	57	4/63
White fir	Pong and Wilcox (147)	1- 1-3/4	15-16	160	140	--	174	--	106	--	60
White fir	J. C. Ward3/	1-3/4	15	180	170	155	150	170	105	66	73
Sugar pine	J. C. Ward3/	1-1/2	15	120	5/75	194	226	204	148	51	72
rdwoods:6/											
Aspen	Cech (36), Huffman (86)	1-3/4	15	140	133	170	4/210+	140	175	--	--
Quaking aspen	J. C. Ward (200)	1-3/4	15	180	170	115-128	179	76-122	90	81-106	115
Eastern cottonwood	J. C. Ward3/	1-1/8	7	180	170	144	75	131	85	--	--
American elm	J. C. Ward 3/	1-1/8	7	120	113	106	134	90	121	69	113
California black oak	Ward and Shedd (205)	1-1/8	7	120	115	95	387	--	--	85	379
Northern red oak	J. C. Ward3/	1-1/8	7	125	121	97	324	--	--	86	312

Comparisons are within kiln runs and not among kiln runs or between species.
DB = dry bulb temperature; WB = wet bulb temperature.
J. C. Ward, unpublished data on file at U.S. Forest Products Laboratory, Madison, Wis.
Extrapolated from published data.
Kiln vents open with steam sprays off.
All wetwood developed honeycomb, collapse, or ring failure or a combination of these.

able 5--Drying times for green veneer with wetwood compared with veneer containing normal sapwood and heartwood

pecies	Source of data	Veneer specifications: Thickness	Veneer specifications: Dried moisture content	Dryer temperatures	Wetwood: Green moisture content[1]	Wetwood: Drying time	Sapwood: Green moisture content[1]	Sapwood: Drying time	Heartwood: Green moisture content[1]	Heartwood: Drying time
		Inch	Percent	°F	Percent	Minutes	Percent	Minutes	Percent	Minutes
alsam fir	Dokken and Lefebvre (48)	1/10	4	300	154	18-1/2	201	15-1/4	76	11
	Dokken and Lefebvre (48)		4	450	154	7-3/4	201	7-1/4	76	5-1/2
	Dokken and Lefebvre (48)	1/6	4	300	154	35	201	31	76	25-1/2
	Dokken and Lefebvre (48)			450	154	15	201	14-1/4	76	9-1/2
ite fir	Vern Parker2/	1/8	5	3/	150	10	150	8	--	4/

Average value.
Superintendent, Plywood Mill, Bendix Corp., Martell, Calif., personal communication to W. Y. Pong.
4-stage gas jet-dried: 450°, 450°, 400°, and 350°F.
Heartwood dried according to sapwood schedule of 8 minutes will be overdried with a moisture content of 1 percent.

2. The wet stock can be sorted and redried after a normal kiln run. This approach will increase drying and handling costs for the wetwood lumber. For white fir dimension lumber containing wetwood, redrying can result in a 40-percent increase in the kiln-drying costs.[23]

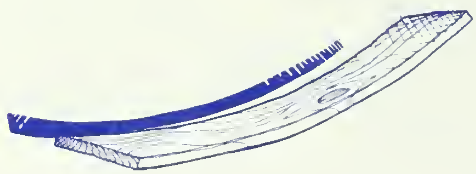
3. Boards greater than 19-percent MC can be marketed as surfaced green lumber and less return will be received for the product. For hem-fir dimension lumber, this can amount to approximately $26 per thousand board feet in selling price (149), not to mention drying and extra handling losses. Shipping weights and the resulting shipping costs of green lumber are important considerations in this third alternative. In table 6 are calculated weights for 1,000 board feet of white fir at different moisture contents. Also included are costs for shipping this lumber to Los Angeles and Chicago from Portland, Oregon. The price differential of $26 between green and dry lumber barely offsets the shipping cost differential of dry lumber (15 percent) and green lumber (150 percent) to Los Angeles but not to Chicago.

[23] Donald O. Prielipp, general manager, Roseburg Lumber Co., Anderson Division, Anderson, Calif., personal communication to J. C. Ward.

Table 6--Freight costs for shipping white fir lumber[1]

Moisture content	Calculated weight per 1,000 board feet	Cost of shipping 1,000 board feet: To Los Angeles (base rate, $1.27/100 pounds)	Cost of shipping 1,000 board feet: To Chicago (base rate, $3.07/100 pounds)
Percent	Pounds	Dollars	Dollars
0	1,271	16.14	39.02
12	1,423	18.07	43.69
15	1,463	18.58	44.91
19	1,513	19.22	46.45
25	1,590	20.19	48.81
75	2,226	28.27	68.34
100	2,543	32.30	78.07
115	2,734	34.72	83.93
150	3,178	40.36	97.56

[1] F.o.b. Portland; base rates (Dec. 15, 1978) are for railroad shipments of 85,000 pounds or less (Western Wood Products Association, Portland, Oreg.).



4. The lumber can be dried by a normal schedule and not sorted for wet stock. All boards, both above and below 19-percent MC, would be surfaced and sold as kiln dried. This option could be exceedingly costly if the volume of wet stock exceeded the 5-percent limitation (210) and was detected by the buyer and reinspection by the grading association requested. Not only would the surfaced lumber have to be resorted, regraded, and metered for moisture, but the boards that exceeded the maximum allowable moisture would be considered substandard surfaced green and regraded accordingly. Losses in excess of $50 per thousand board feet are possible with reinspection.

5. The green lumber could be segregated into uniform drying sorts (sapwood, heartwood, and wetwood or sinker) and each then dried under different kiln schedules or treatments. This presorting would minimize the extremes in final moisture content within a given kiln charge and has long been advocated for western softwoods (103, 178), particularly white fir[24/] (101, 177, 179; also see footnote 17), western hemlock (110), redwood (138), and incense-cedar (152). Presorting would minimize energy costs. With the energy crisis, it becomes imperative that costs of energy used in drying and redrying wetwood be given careful consideration, especially since 60 to 70 percent of the total energy used in manufacturing most wood products is consumed in drying (43).

Commercial presorting of green lumber for drying by visual detection and hand methods has been used with some success for western hemlock (110), incense-cedar (152), and California white fir (145, 178, 215). For presorting to be effective, however, each board must be examined on all sides during the segregation operation. Under high production mill conditions, manual presorting is generally not possible. Examination of individual boards will also be limited where tray and drop sorters are used. Mechanical, electrical, and optical instruments for automatic presorting of wetwood lumber on a commercial scale have not been developed (207).

[24/] J. Steel. 1953. Kiln drying white fir. Wood drying committee news digest. (Aug.) 3 p. Forest Products Research Society, Madison, Wis.

Another obstacle to obtaining maximum effectiveness in presorting is the mixture of wetwood and normal wood that occurs in many boards on the commercial green chain (110, 147). It is possible to develop optimum schedules for drying boards having mixtures of normal sapwood and heartwood with wide differences in green moisture content (161), but not for mixtures of sapwood and wetwood even though there may be little or no difference in green moisture content (162). Studies of white fir indicate that boards containing mixtures of wetwood, sapwood, and corky heartwood will have more drying and surfacing problems than boards that dry more uniformly (147, 215).

Steaming of green lumber before drying increased the drying rate of wetwood from white fir (175) and redwood (52), but was not effective with western hemlock (110) or eastern hemlock (see footnote 8). The chemical nature of extractives in the wetwood seems to be an important factor controlling the effectiveness of presteaming.

Chemical Brown Stain

Chemical brown stain in wetwood is an especially serious defect in lumber, veneer, and wood fiber products graded on appearance. Brown stain also affects the marketability of softwood dimension lumber because consumers think the wood looks decayed. Wood decay fungi are not considered causal agents for chemical brown stain (51, 56, 85, 103, 148, 151). Brown stain in wetwood usually develops in the zone between sapwood and heartwood or within bacterially infected heartwood. Sapwood of many species develops brown stain if taken from logs stored for an extended time under humid conditions. Brown stain developed in eastern white pine lumber from logs stored in the woods for 42 and 93 days, but not in lumber sawn and seasoned within 24 hours of felling (14). Depth of stain in boards increased as storage time increased. Extended storage of ponderosa pine and sugar pine logs under water sprays will initiate development of brown stain in sapwood boards and further intensify darkening in wetwood zones.[25]

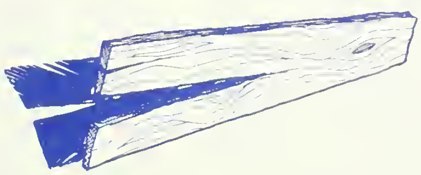
Timber species noted for developing chemical brown stain during drying usually tend to have wetwood. Processing problems associated with chemical brown stain in lumber are considered important commercially for the following species: sugar pine, eastern and western white pines, ponderosa pine, Pacific silver fir, noble fir, western hemlock, redwood, western redcedar, and Sitka spruce (5, 7, 18, 19, 23, 29, 35, 56, 61, 89, 99, 103, 141, 151, 165).

[25] Del Shedd, Quality Control Supervisor, Kimberly Clark Corp., Anderson, Calif., personal communication to J. C. Ward.

Brown stain can develop in both air-dried and kiln-dried wood, but it is usually mo pronounced under warm, humid kiln schedules. Considerable brown stain can occur in boards air dried at temperatures as low as 80°F (141). Chemical brown stain may also develop just below, but no on the surface of, air-dried lumber and will not be noticed until after the boards are surfaced (155). This concealed brown stain, referred to as yard brown stain, h been observed in ponderosa pine, sugar pine, and the white pines (85). Wetwood prone to developing brown stain should be segregated from other green lumber. The wetwood stock would be air dried; the normal stock, kiln dried. For minimum development of brown stain during air drying, the lumber should be from freshly felled trees and drying should be fast, w relative humidities below 65 percent (14, 61, 66, 141, 155).

If faster drying of wetwood is desired or presorting is not feasible, reduction or prevention of chemical brown stain during kiln drying may be accomplished by either manipulating kiln schedules or dipping th green boards in enzyme-inhibiting or antioxidant solutions. There are, howeve drawbacks to these preventive methods tha are important.

›w initial temperatures in kilns and low ımidities with good air circulation are ecessary to successfully reduce brown :ain or prevent it (23, 29, 99, 102, 105, l1). Rosen (156) found that high ›mperature jet drying eliminated brown :ain in cottonwood, but the wetwood ›llapsed and checked. With low ›mperatures, the kiln usually has to be nted to attain low relative humidities 9, 102, 103). Venting dry kilns results a great waste of energy. Sometimes the ln doors must be opened during drying to wer the humidity, and the duration of the nting can be from 3 days to 1 week. nipulating kiln schedules has not been ccessful in controlling dark stains in dwood unless the lumber was first steamed , 52, 54). Solvent drying of redwood th acetone has been proposed for imination of stains (6).



Kln schedules to prevent stain are not aways successful if the drying operation i regulated either on a time basis or on kln samples containing only normal wood. Fgure 3 shows chemical brown stain that dveloped only in sugar pine boards cntaining wetwood but not in sapwood or nrmal heartwood. These boards were dried uler an antistain schedule based on the a'rage drying rate of boards with normal wod. The operation could have been based or the drying rate of the wetwood boards, bu the normal boards would have been over-dred and the subsequent surfacing of these bcrds would result in planer splitting. Th solution is to segregate the normal bcrds from the wetwood boards and then dry eah board sort under different schedules.

Dipping green lumber in enzyme-inhibiting or antioxidant solutions usually prevents brown stain and permits higher initial kiln temperatures and humidities (34, 35, 61, 102, 103, 170, 182). Such reagents will not reduce brown stain if they are not able to sufficiently penetrate the wood surface during the dip treatment (141). Proper use of antistain dips results in substantial reductions in drying and energy costs, but most chemicals used are highly toxic to humans. Because of Occupational Safety and Health Administration inspections, the dipping of boards in brown stain retardant solutions has been discontinued by many mills.

Stain-producing extractives from wetwood can cause problems with finishes. Figure 4 shows the undesirable darkening of a lacquer finish from an underlying oak laminate containing wetwood. Water-soluble extractives in wetwood of redwood and western redcedar cause serious problems when stains penetrate finishes on exterior siding. Connors found that extraction of sequirins from the redwood can effectively prevent the problem.[26] On a commercial scale this treatment could be cumbersome with lumber, and a disposal problem would be created. Connors also found that dipping the boards in lead acetate before applying finishes is effective but expensive, and lead is now prohibited for such use.

The chemical precursors causing brown stain problems in drying wetwood in western hemlock lumber are also responsible for problems when this species is used for ground woodpulp (15, 17). The cost per ton of raising the brightness of the ground hemlock woodpulp can be increased by 15 to 20 times when brown stain occurs. Aspen wetwood is objectionable for pulp because of added bleaching costs (79).

[26] G. L. Connors. 1968. Considerations for reducing extractives staining in redwood. Office report, 11 p. U.S. Forest Products Laboratory, Madison, Wis.

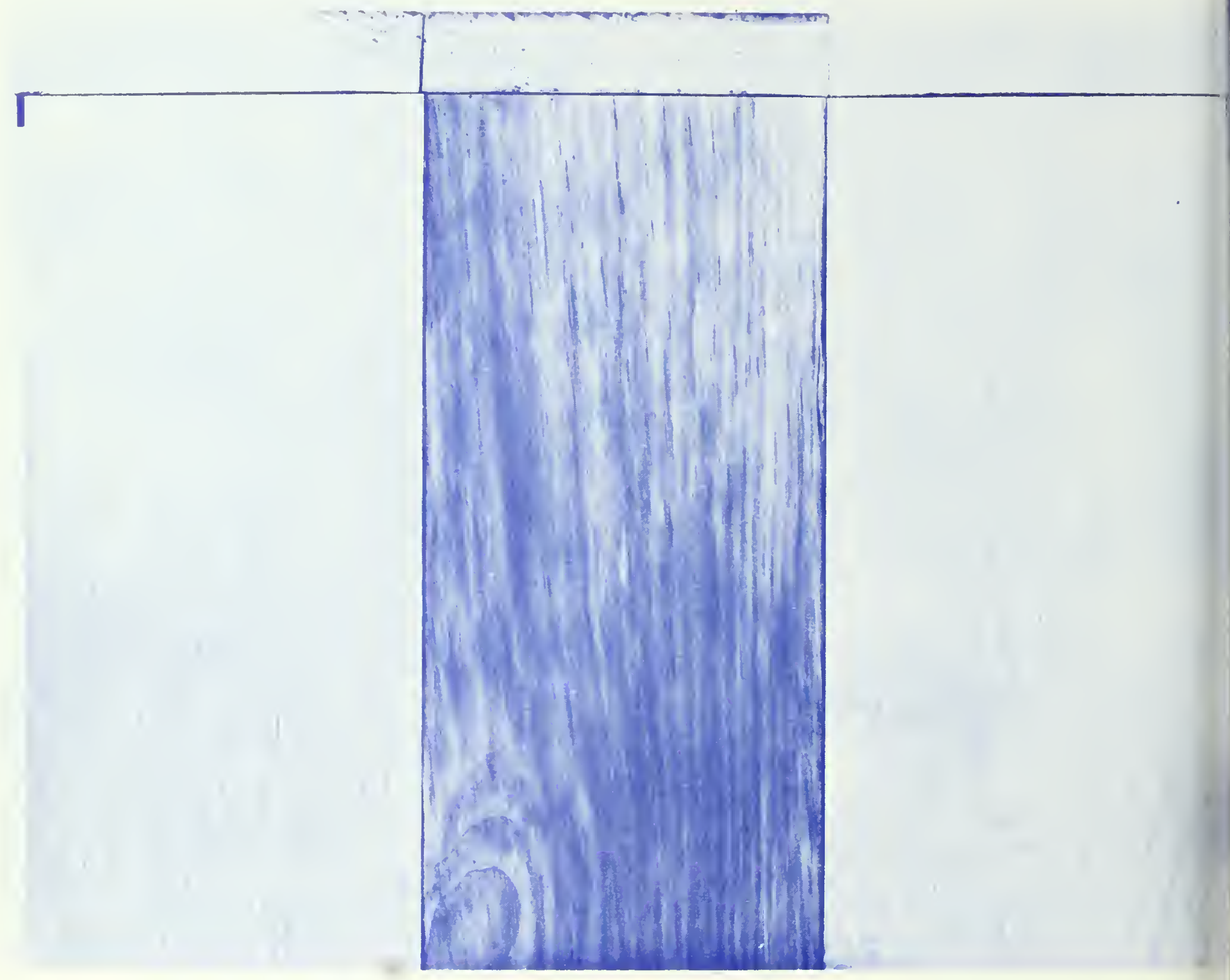
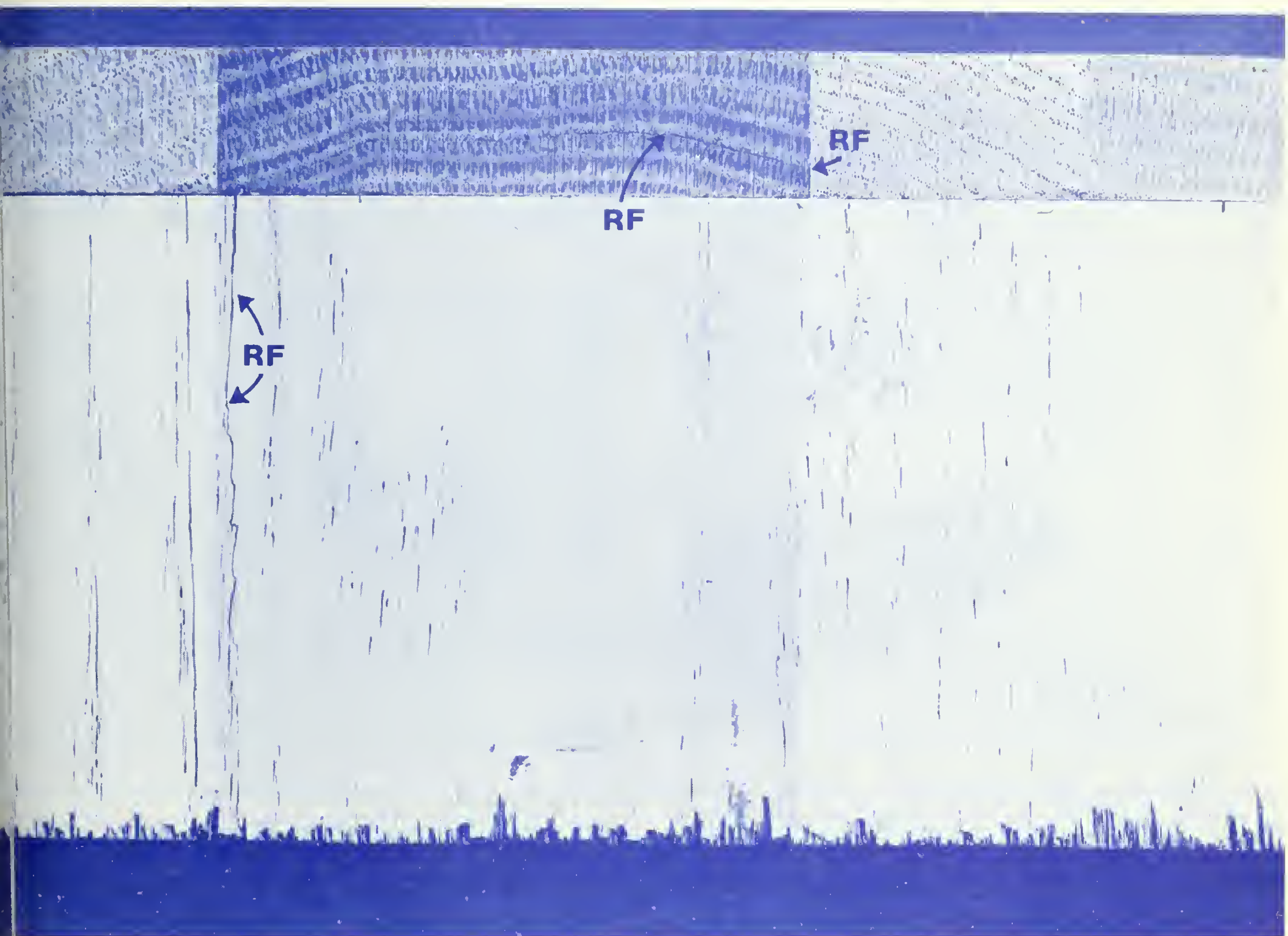


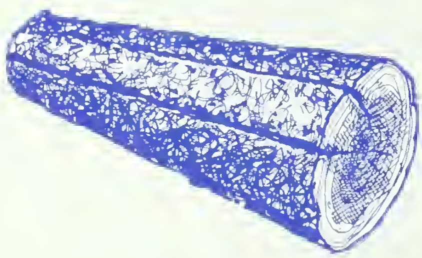
Figure 3.--Kiln-dried sugar pine shows chemical brown stain in center board that contained wetwood but not in boards with sapwood (left) or normal heartwood (right). End sections (top) were cross cut from rough, dry boards, and one-sixteenth inch was planed from board surfaces (bottom).



ure 4.--Darkening of a white lacquer finish overlying a kiln-dried red oak laminate otaining bacterial wetwood. Ring failure (RF) within the laminate extended to the uface during air drying of the lacquer finish.

Plywood and Reconstituted Boards

Little is known about the effect of wetwood on the quality of plywood and reconstituted wood products. We believe that investigations of the use of wetwood in these products may well provide insight on unsuspected causes of some processing problems. Also, these products are increasingly promoted for use as components in light frame construction (184), and the effect of wetwood on strength properties should be investigated.



There are several ways that wetwood causes problems with the processing and quality of plywood. Shake and frost cracks cause "spinout" of bolts on the lathe, resulting in splits and splintering of veneer (71, 79, 125, 126). Commercial experience indicates that wetwood in "sinker" logs of species like redwood is undesirable for veneer because of cutting and drying problems (125). The assembly-time tolerance of conventional plywood adhesion restricts the moisture content of veneer to defined upper and lower limits. Control of moisture content in veneer from wetwood is a major technical problem and can lead to "undercured," "washed out," or "starved" glue lines and to "blows" and "blister" in the pressing operation (32). Nearly all the "blows" during production of white fir plywood are related to wetwood in the veneer.[27]

[27] Vern Parker, Bendix Corp., Martell, Calif., personal communication to W. Y. Pong.

The effect of wetwood on the strength of the glue bond is usually associated with wet pockets, and there is a dearth of information on the influence of extracti and pH. Poor adhesion because of uneven distribution of moisture in dried veneer containing wetwood has been reported for eastern cottonwood (191), western hemloc (79), balsam fir (32), and white fir (126). Oxidation stains are objectionab characteristics for face veneers, and th stains may possibly interfere with prope adhesion of the glue to the wood. Some wetwood species most susceptible to oxidation stains during production of plywood are: sugar pine, western white pine, ponderosa pine, Jeffrey pine, red maple, tanoak, bottom-land oaks, tupelo, and willow (126).

A small amount of research data exists t suggest that wetwood may lower the stren properties of reconstituted boards that include particle board and hardboards. Table 7 shows that wetwood from aspen an western larch will not make as strong a flakeboard as normal sapwood and heartwood.[28] Linear stability was not adversely affected by wetwood, but thickness swelling was greater for aspen boards containing wetwood and least for larch. Wet process hardboards from aspe wetwood have a lower modulus of elastici modulus of rupture, and internal bond strength than boards from sapwood (67). Dimensional stability of the hardboards from wetwood was greater than boards fro sapwood, however.

[28] J. C. Ward and J. Chern. 1978. Comparative properties of flakeboard mad from normal wood and from bacterial wetw of trembling aspen and western larch. A preliminary report. 6 p. U.S. Forest Products Laboratory, Madison, Wis.

le 7--Physical and mechanical properties of 1/2-inch-thick flakeboards[1] from normal wood and wetwood of
mbling aspen and western larch[2]

cies and e of wood	Specific gravity[3]		Mechanical properties				Swelling in 30- to 90-percent relative humidity	
	Solid wood	Flakeboard	Moisture content	Modulus of rupture	Modulus of elasticity	Internal bond	Linear	Thickness
			Percent	Pounds per square inch	Thousand pounds per square inch	Pounds per square inch	Percent	Percent
en (Wisconsin):								
apwood	0.474	0.657	7.2	5,541	692	128	0.07	6.88
etwood[4]	.504	.652	7.4	4,499	618	95	.08	9.58
en (Colorado):								
eartwood	.35	.715	6.2	6,390	994	76	.14	9.56
etwood[5]	.34	.634	6.8	4,335	677	48	.14	12.76
ch:								
apwood	.480	.652	9.3	4,992	655	89	.09	11.45
eartwood	.454	.648	8.9	4,520	635	112	.10	9.87
etwood[6]	.701	.628	9.2	3,542	549	74	.08	7.80

/ oards made from 0.02- by 2.0-inch flakes with 4-percent phenolic resin.
/ ta from J. C. Ward and J. Chern. 1978. Comparative properties of flakeboard made from normal wood and from
aerial wetwood of trembling aspen and western larch. A preliminary report. 6 p. U.S. Forest Products
a ratory, Madison, Wis.
/ ecific gravity of wood based on ovendry weight and ovendry volume. Specific gravity of board based on ovendry
e ht and volume of board at mechanical test moisture content.
/ cterial wetwood formed where sapwood changes to heartwood.
/ cterial wetwood formed in previously developed, normal heartwood.
/ rmed from microbially infected inner sapwood--heavily saturated with water-soluble extractives that included
ra inogalactans.

›rrosion of Kilns

eorts of accelerated corrosion of dry ins have increased in frequency in recent ers. Most cases of corrosion can be rced to highly acid atmospheres within h kiln during drying. Not only are metal als, pipes, fasteners, etc., attacked by hs corrosive mixture of air, but nrotected concrete (16) and wood stickers ar also subject to accelerated le erioration. Several explanations can be gi en. Drying charges of green lumber a her than partially air-dried lumber considerably increases the liability of wood to evolve corrosive acid vapors (10, 11, 39). Use of high temperature schedules in drying green wood increases corrosion. Contact between dissimilar metals in the kiln, such as aluminum and iron in an acidic atmosphere, will produce a "battery effect" and corrosion of metal will be greatly accelerated (16). The drying of wood treated with aqueous solutions of preservatives will cause corrosion problems (39).

Although investigations are needed, we believe that the presence of wetwood in green lumber charges can be a definite factor in many reported cases of increased kiln corrosion. Oak, hemlock, and the true firs are species likely to have wetwood with a pH as low as 3.5. Metal corrosion is greatly accelerated by a pH of 4.0 or less (10, 11), and acidic vapors of pH 3.5 will attack concrete (16). Barton (16) related the presence of normally occurring chelating compounds in the extractives of western redcedar with the corrosion of iron but not of aluminum in dry kilns. Not all charges of western redcedar caused chelation corrosion.

Wetwood in western hemlock lumber may be an important factor in kiln corrosion. In 1951, MacLean and Gardner (135) reported that an increase in the deterioration of wooden dry kilns was due to increased use for drying western hemlock lumber. An acid condensate of aqueous vapors from the hemlock resulted in deterioration of the cellulose in kiln boards and corrosion of metal fittings. Although Douglas-fir heartwood is acid, the vapor condensates were not as acid as those from hemlock. Also, Douglas-fir heartwood has a higher content of resin, and the vapor condensates form a protective layer. The acid vapors from drying one or two charges of hemlock will remove this protective layer of Douglas-fir condensates. Most lumber is now dried in metal kilns, and Barton (16) estimates that at least 90 percent of the corrosion in these kilns is caused by vapor condensates.

Research Needs

Wetwood is responsible for substantial losses of wood, energy, and production expenditures in timber-using industries. There is a clear need to more thoroughly assess these losses and to find ways of eliminating or minimizing them.

An effective research program on wetwood should include planning short- and long-term solutions to the overall proble and providing for them. Solid wood products, particularly lumber and veneer, are most adversely affected by processin defects related to wetwood. Lumber and veneer are expected to be prime economic products from future timber harvests (97). In the long term, the best solution to th wetwood problem may well result from timb management research to prevent future occurrences of wetwood.

Short-Term

The initial research effort must be primarily concerned with attacking existi utilization and processing problems, but i should also provide a scientific basis fo long-term research planning. A short-ter research program should concentrate on: (1 assessing the occurrence of wetwood in standing timber and its effect on product yields and losses, (2) defining the chemical and physical properties of wetwo as a basis for detecting and segregating affected wood products, and (3) developin optimum utilization and processing method for timber and wood products containing wetwood. Item 1 would be the pivotal are of endeavor for the short-term research program and also the area most likely to provide continuity with long-term researc

ese studies should be carried out operatively by timber managers, timber ocessors, and forestry researchers. The nagers would provide the timber and the ll operators the processing facilities. searchers would record information on nber quality for selected sample trees. cked logs from the sample trees would be llowed individually through the milling ocess and information, including the ade and amount of product cut from each g, tallied. The yield data would be mpiled and analyzed in conjunction with nber quality data to provide the basis r predicting the product yield from milar timber. Measurements of wetwood in e timber and the resultant defects in th green and dried wood products would be corporated into the beginning and final ases of a product yield study.

tdies on timber products and yields are portant to the initiation of research on ewood. Now we can only guess, but with ce confidence, that the utilization and rcessing problems associated with wetwood r costing the wood-using industries many ilions of dollars annually. No ttistical or economic surveys have en initiated either for the purpose of eermining the amount of wetwood in timber tnds or for estimating the losses that nuestionably result from the processing of ewood timber. Government agencies have o initiated and carried out the necessary uveys on wetwood because they are not wre that a problem exists; this stems agely from industry's reluctance to make oncerted effort to publicly recognize h problem.

The major reason the wetwood problem is not publicized is that most foresters and many wood processors have not related defects--such as shake and frost cracks in trees and collapse and honeycomb in lumber--to wetwood. This is understandable because, until just recently, wood scientists have related the unexpected occurrence of honeycomb and ring failure when drying wetwood lumber to an inherent and perfectly normal variability in wood properties (75). Thus, lumber grading associations have been reluctant to recognize wetwood as a precursor to processing defects when even scientific experts are often unable to discern it in green lumber. In fact, there appears to be more recognition of wetwood and its problems by sawmill and dry kiln operators and furniture manufacturers than there is in the scientific community.

Logical species for the initial short-term studies are western hemlock, western true firs, eastern oaks, and the white pines, including sugar pine. These species are very susceptible to formation of wetwood and constitute a sizable volume of timber on commercial forest lands in the United States (192, 193). Comparisons of these species with other commercial species are shown in table 8. In spite of their susceptibility to wetwood, western hemlock, western true firs, eastern oaks, and white pines are tree species of high value and capable of producing valuable lumber items (table 9).

Table 8--Comparison of softwood and hardwood timber volumes from USDA Forest Service (192), and susceptibility of species to formation of wetwood

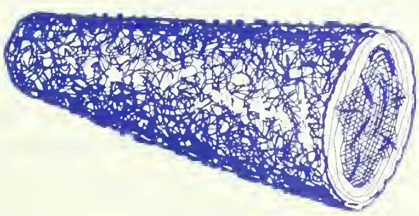
Species	Sawtimber volume		Growing stock volume		Wetwood class[1/]	Study priority[2/]
	Billion board feet	Percent	Billion cubic feet	Percent		
Western softwoods:						
Douglas-fir	520.640	27.3	96.861	22.4	1	
Western hemlock	251.012	13.2	47.540	11.0	3	1
True fir	218.772	11.5	45.326	10.5	2-3	2
Ponderosa and Jeffrey pine	189.897	10.0	38.292	8.9	1-2	
Spruce (Sitka, Engelmann, etc.)	132.225	6.9	26.296	6.1	1	
Lodgepole pine	65.273	3.4	25.530	5.9	1	
Sugar pine	23.520	1.2	4.344	1.0	2	4
Western white pine	20.872	1.1	3.993	.9	2	4
Western redcedar	40.897	2.2	8.106	1.9	2	
Western larch	31.256	1.6	6.753	1.6	2	
Redwood	23.627	1.2	4.428	1.0	2	
Other western species	31.362	1.7	6.886	1.6	1	
Total	1,549.353	81.3	314.355	72.8		
Eastern softwoods:						
Shortleaf and loblolly pine	196.502	10.3	53.571	12.4	1	
Longleaf and slash pine	44.248	2.3	13.855	3.2	1	
White and red pine	26.874	1.4	8.349	1.9	1-2	
Spruce and balsam fir	23.485	1.2	17.322	4.0	1-3	
Cypress	19.112	1.0	5.033	1.2	1	
Eastern hemlock	16.178	.9	5.781	1.3	3	
Other eastern species	29.534	1.6	13.611	3.2	1	
Total	355.933	18.7	117.522	27.2		
Total softwoods	1,905.286	100	431.877	100		
Eastern hardwoods:						
Red oak	106.217	20.6	39.309	18.1	2	3
White oak	78.689	15.3	32.099	14.8	1-2	3
Hickory	30.914	6.0	12.583	5.8	1-2	
Soft maple	23.871	4.6	15.070	6.9	2	
Hard maple	25.757	5.0	11.731	5.4	1	
Sweet gum	26.318	5.1	10.528	4.8	2	
Tupelo and black gum	25.506	5.0	9.817	4.5	2	
Yellow poplar	25.093	4.9	8.570	4.0	2	
Cottonwood and aspen	16.771	3.3	12.096	5.6	2-3	
Ash	15.957	3.1	7.736	3.6	2	
Beech	15.649	3.0	5.794	2.7	2	
Black cherry	6.904	1.3	3.488	1.6	1	
Basswood	8.502	1.6	3.434	1.6	1	
Yellow birch	7.324	1.4	3.249	1.5	2	
Other eastern species	46.313	9.0	22.178	10.2	1-2	
Total	459.785	89.2	197.682	91.1		
Western hardwoods:						
Red alder	24.842	4.8	7.638	3.5	1-2	
Cottonwood and aspen	12.077	2.3	5.043	2.3	2-3	
Oak	3.064	.6	1.606	.8	2	
Other western species	15.713	3.1	5.043	2.3	1-2	
Total	55.696	10.8	19.330	8.9		
Total hardwoods	515.481	100	217.012	100		

1/Class 1 species are least affected with wetwood; class 3 are most susceptible.
2/1 = highest; blanks indicate species with a priority lower than 4.

le 9--Values of sawtimber stumpage and typical kiln-dried lumber prices for tree species with high priority for incorporation a research program on wetwood

cies	Study priority1/	Value of sawtimber stumpage2/	Kiln-dried lumber		
			Grade	Thickness	1978 price3/
		Dollars		Inches	Dollars per thousand board feet
tern softwoods:					
estern hemlock	1	46,245,409	Finish FG, C and Better selects	4/4	569
ountain hemlock	1	344,395	No. 2 and Better, Hem-fir Dimension	8/4	244
Total		46,589,804			
hite, grand, and miscellaneous firs	2	24,234,647			
oole fir	2	5,046,826	Moulding and Better, rough dry	5/4, 6/4	526-562
hasta red fir	2	2,097,222	No. 2 and Better Dimension	8/4	236
ubalpine fir	2	601,378			
Total		31,980,073			
ugar and western white pine	4	40,004,600	C and Better Selects, S2S	4/4, 5/4, 6/4, 8/4	944-1,010
			Moulding, S2S	4/4, 5/4, 6/4, 8/4	463-761
tern hardwood:					
ak	3	1,328,917	No. 1 Common and Better	4/4, 5/4	800-1,100

/ = highest.
alue of sawtimber stumpage sold from National Forests in 1976 (143).
/eraged prices for softwood (Western Wood Products Association, Portland, Oreg.) and range of prices for oak (Hardwood ket Report, Volume 56, Memphis, Tenn.).



aerial for the corollary studies on ewood properties and processing should be eected from sample trees, logs, and wood rducts of the product and yield studies. tdies of wetwood properties should be eigned to aid development of practical and cirate methods for detecting wetwood in iber and solid wood products in the green odition. Studies on processing methods hild determine, both qualitatively and uitatively, the wood losses, grade hnges, and energy requirements for rducing end products containing wetwood so th comparisons could be made with products coraining normal wood. Results and edback from the corollary studies would ncease the efficiency and accuracy of iber quality evaluation and prediction of rduct potential for the commercial wood rcessor.

High priority should be given to three items of concern in the area of research to develop improved processing methods for timber and wood products containing wetwood:

1. Develop an accurate and fast method for identifying wetwood in green lumber and veneer to segregate the pieces into drying sorts.

2. Determine optimum methods for processing sorts of lumber and veneer containing pure and mixed amounts of wetwood and normal wood.

3. Compare mechanical strength properties of lumber containing wetwood with similar lumber of normal wood content for light frame construction.

There are good possibilities to design studies which could examine all three items.

Investigations to determine optimum methods of drying boards and veneers containing wetwood should probably be conducted in tandem with investigations to characterize and sort these products before they are dried. It would be useful to design these processing studies so that any development of drying defects could be related back to micro-organisms in the tree. The spread of bacteria from wetwood zones to sapwood during log storage needs to be investigated with respect to formation of chemical brown stain and changes in permeability of the sapwood. Definitive biochemical studies of contributing micro-organisms can also be considered a long-term research need.

A particular short-term research need must be the processing of boards and veneer containing mixtures of wetwood and normal wood. As was pointed out for white fir (147) and western hemlock (110), boards containing wood of a mixed drying sort present additional problems for drying and planing which have been ignored. Green boards and veneer containing mostly wetwood, if properly presorted, can be dried under special schedules. No data are presently available, however, for delineating characteristics of mixed wood sorts that would properly identify and permit presorting these products for drying. Techniques for drying mixed wood boards and veneer for optimum yields and energy consumption must be considered a short-term need of high priority.

The influence of wetwood on strength properties of lumber for light frame construction is not known. We can safe[illegible] assume, though, that wetwood probably h[illegible] detrimental effect because of the freque[illegible] occurrence of deep surface checks, honeycomb, and shake in the dried lumbe[illegible] that reduces the resistance to shear. Shake is closely limited in stress-grade[illegible] lumber for construction, particularly i[illegible] members subject to bending (194). The [illegible] in table 7 suggest that wetwood may caus[illegible] particleboard intended for structural purposes to have lower strength values [illegible] boards made entirely from normal wood. [illegible] importance of investigating the influenc[illegible] of wetwood in structural lumber and othe[illegible] building components cannot be overemphasized. According to Suddarth (184), the light-frame building is the predominant form of construction worldwide. Consequently, technological gains in light-frame construction can vitally affect large segments of the world's population.

Long-Term

The objectives of a long-term research program should be mainly concerned with attacking the causes of wetwood. Additi[illegible] basic research aimed at reducing energy [illegible] wood losses during the processing of wet[illegible] may also be needed. Specific plans for long-term research will depend somewhat [illegible] the initial information derived from short-term research, together with recommendations from workers in the fiel[illegible] of forest biology and timber management.

owledge of specific patterns and location wetwood in standing trees gained largely om short-term research will provide the sis for planning long-term investigations the causes of wetwood. The role of cro-organisms, especially anaerobic cteria, need to be investigated. To be aningful, though, research on microbiology st be coordinated with investigations of her possible causes. There is a need to vestigate possible contributions by the llowing agents: insects, fungi, mistletoe, ygen and water stress, fire, and chanical wounds associated with timber agement and recreational uses of the est.

ntification and biochemical character-ation of the bacterial populations sociated with wetwood can help to solve rent wood processing problems and provide asis for future control of wetwood mation in trees. The biochemical tribution of pectolytic and nyloxidizing bacteria to shake and frost cks in trees and to surface checking, eycomb, collapse, ring failure, and mical brown stain in wood products needs be more thoroughly defined and related to initial formation of wetwood.

It is important to explore the possibility that bacteria in wetwood may enhance its subsequent decay by fungi if anaerobic conditions are lost, such as by frost cracks. Hartley et al. (79) noted that fungal wood decay can be accelerated by the presence of bacteria but did not consider the possibility that wetwood bacteria may provide a source of nitrogen and vitamins for fungal growth. Nitrogen-fixing bacteria have been considered in more recent papers[29/] (3, 4, 22). Nitrogen fixation by bacteria has even been associated with sporophores of decay fungi on western hemlock trees (118). In addition, Bourchier (25) found that bacteria from wetwood can produce vitamins which enhance the growth of wood-decaying fungi.

Studies of bacterial populations in wetwood must also be concerned with distinguishing inocuous plant and soil bacteria from pathogenic and fecal coliforms by serology, cell wall analysis, and deoxyribonucleic acid homology studies.[30/] The presence of coliform bacteria in living wood tissues (13) can be a problem in some uses of wood products, such as redwood for water storage tanks (166).

[29/] S. D. Spano, M. F. Jurgensen, M. J. Larsen, and A. E. Harvey. 1978. Nitrogen fixation in decaying Douglas fir residue. Paper presented at 70th Annual Meeting of the American Society of Agronomy, 11 p. Madison, Wis.

[30/] J. G. Zeikus, University of Wisconsin, Department of Bacteriology, Madison, personal communication to J. C. Ward.

Once the causes of wetwood are understood, there are two methods for control: direct and indirect. Long-term research should evaluate the relative merits of each method. In the practice of forestry, direct control of tree diseases and insect injuries is generally not as practical or economical as indirect measures of control. Direct methods, such as chemical spraying, are more practical with agricultural crops than with long-term timber crops which have a lower value per unit of ground. Still, direct measures of control have been successfully used in forest management and must be considered for preventing wetwood. Tree species susceptible to wetwood during early stages of growth may require aerial spraying and soil fumigation. Special thinning methods and fertilization may also be needed in these young-growth stands, but wetwood is sometimes reported to be more prevalent in dominant, fast-growing trees than in suppressed or slow-growing trees (45, 59, 181).

The rotation age for sawtimber could be reduced for species that develop wetwood with advancing age. When guidelines are developed for this type of control, it is also necessary to determine the influence of site factors and genetic makeup of the tree species on its resistance or susceptibility to wetwood with aging. If wetwood develops in young trees before sawtimber size is reached, direct control measures could be aided by research on the utilization and processing of the timber. Pole-size or presawtimber stands might be converted into products of higher unit value than the present end uses for pulp and paper. The development of more efficient drying and machining methods could even allow young trees with wetwood to profitably grow to sawtimber size.

With current economic conditions, the g of timber managers must be to grow sawtimber that will not develop wetwood before financial maturity. Indirect or preventive control measures necessary t achieve this goal can be obtained from forest biology and tree genetics resear This research must correlate the mechan of genetic resistance to wetwood format with the influences of site and cultura practices. Benefits from a long-term research program could include:

1. Determination or development of tree that are genetically resistant to forma of wetwood.

2. Determination of growing conditions that will prevent or minimize formation wetwood in susceptible tree species bef the trees reach financial maturity for sawtimber.

3. Development of cultural and harvesti practices that will minimize the tenden for wetwood to form in residual trees o regeneration.

onclusion

om this overview, it is apparent that twood is responsible for substantial sses of wood, energy, and production penditures in the forest products dustry. These losses result from a raw terial anomaly that in the past has ther not been recognized or has been nored. Though there is a definite need assess more thoroughly these losses and find ways of eliminating or minimizing em, there is also a need to examine the use; i.e., wetwood. The fact that more d more problems in utilization and ocessing of timber are recognized as lated directly or indirectly to wetwood early demonstrates the importance of this enomenon.

effective program of research is needed determine the significance of wetwood in ese problems. This program should plan d provide for obtaining both short- and ng-term solutions to the overall oblem. Because of increasing interest in twood, excellent opportunities now exist initiate such a comprehensive research ogram.

ere can be little doubt that the effects wetwood on the forest products industry real, and the impact is far reaching. th dwindling timber supplies, increasing sts of available energy, and a scarcity low cost capital, the timber industry no longer afford to ignore the problems sociated with wetwood, for wetwood has an pact on all these issues.

t is time we examine, in depth, the erimental effects of wetwood during all ses of timber production--from the stump the finished product. Losses related to ewood, which in the past were accepted as at of the package of doing business or hught to be the result of inadequate rcessing, can no longer be viewed in that otext. A fuller understanding of the hracteristics of wetwood, whether in the re, log, or product, will provide timber naagers and processors with the tools to adle the wetwood problem.

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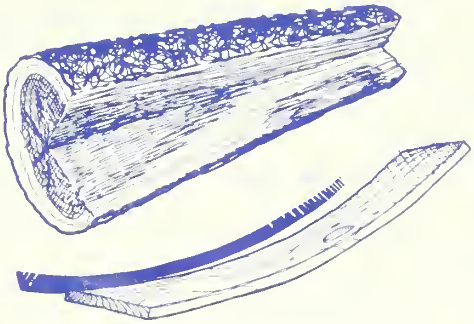

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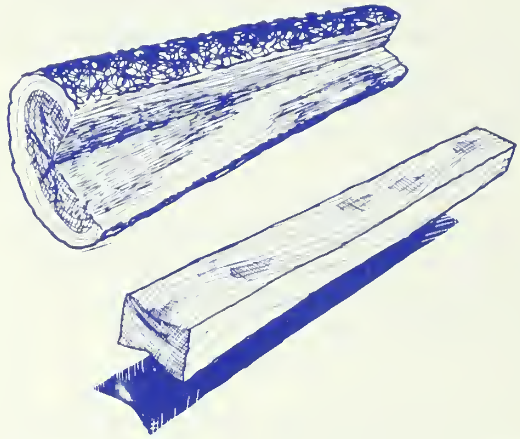

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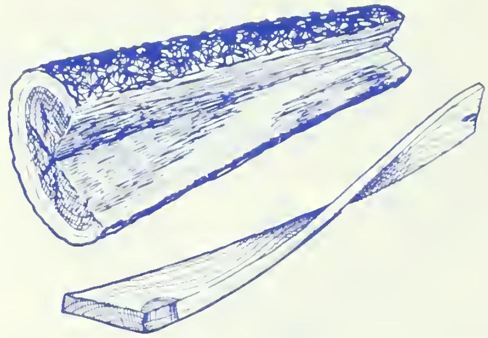

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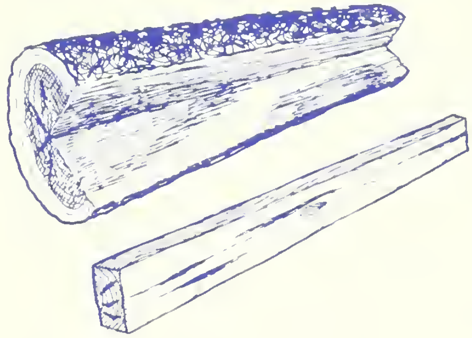

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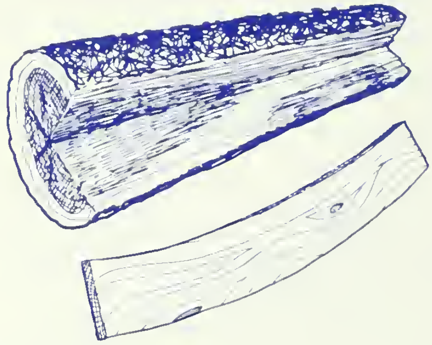

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General Technical Report PNW-113
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11

Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America

PROCESSING MILLS AND CAMPS

DONALD C. SCHMIEGE

USDA FOREST SERVICE
ANADROMOUS FISH HABITAT
PROGRAM

U.S. Department of Agriculture Forest Service
Pacific Northwest Forest and Range Experiment Station

ABSTRACT

For nearly 50 years, effluents from pulp and paper mills have been known to be toxic to fish and other aquatic animals. Lethal concentrations have been determined for several species of fish and other organisms. Many factors--such as water temperature, age of fish, and additional stresses--affect the ability of fish to withstand pollution. Kraft mill wastes are generally more toxic than sulfite wastes. The high biological oxygen demand of sulfite wastes is often more serious than the chemical toxicity of the effluents. Studies on the effect of kraft effluents on invertebrates show that none of them are more sensitive than juvenile salmonids and some species are more resistant. Fish habitat may also be affected by mill stack emissions. High concentrations of sulfur dioxide may damage or kill trees and other vegetation. The effect of logging camps on fish habitat is largely unknown.

KEYWORDS: Pulp/paper industry, toxic effects (biocide), wood wastes, fish habitat, water quality.

USDA FOREST SERVICE
General Technical Report PNW-113

INFLUENCE OF FOREST AND RANGELAND MANAGEMENT ON ANADROMOUS FISH HABITAT IN WESTERN NORTH AMERICA

William R. Meehan, Technical Editor

11. Processing Mills and Camps

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
Forest Service, U.S. Department of Agriculture, Portland, Oregon

PREFACE

This is one of a series of publications summarizing knowledge about the influences of forest and rangeland management on anadromous fish habitat in the Western United States. This paper addresses the effects of processing mills and camps on anadromous fish habitat. Our intent is to provide managers and users of the forests and rangelands of the Western United States with the most complete information available for estimating the consequences of various management alternatives.

In this series of papers, we summarize published and unpublished reports and data as well as observations of resource scientists and managers. These compilations should be valuable to resource managers in planning uses of forest and rangeland resources, and to scientists in planning future research. The extensive lists of references serve as a bibliography on forest and rangeland resources and their uses.

Previous publications in this series include:

1. "Habitat requirements of anadromous salmonids," by D. W. Reiser and T. C. Bjornn.

2. "Impacts of natural events," by Douglas N. Swanston.

4. "Planning forest roads to protect salmonid habitat," by Carlton S. Yee and Terry D. Roelofs.

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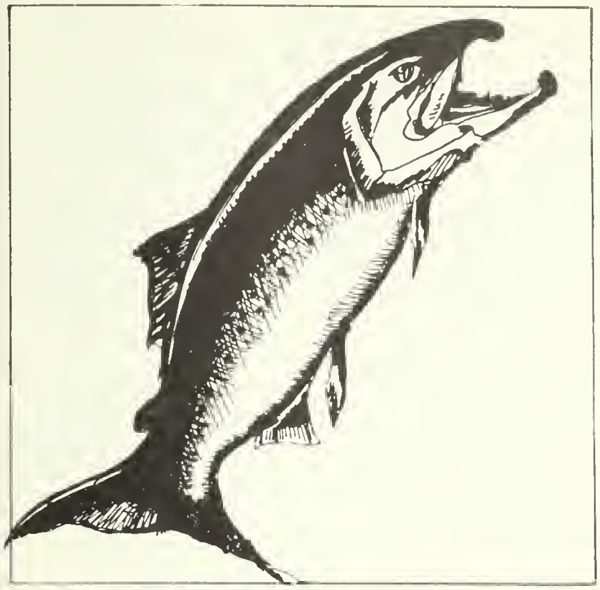
COMMON AND SCIENTIFIC NAMES OF TROUTS, FAMILY SALMONIDAE[1/]

Common name	Scientific name
Pink salmon	*Oncorhynchus gorbuscha* (Walbaum)
Chum salmon	*Oncorhynchus keta* (Walbaum)
Coho salmon	*Oncorhynchus kisutch* (Walbaum)
Sockeye salmon (kokanee)	*Oncorhynchus nerka* (Walbaum)
Chinook salmon	*Oncorhynchus tshawytscha* (Walbaum)
Cutthroat trout	*Salmo clarki* Richardson
Rainbow (steelhead) trout	*Salmo gairdneri* Richardson
Atlantic salmon	*Salmo salar* Linnaeus
Brown trout	*Salmo trutta* Linnaeus
Arctic char	*Salvelinus alpinus* (Linnaeus)
Brook trout	*Salvelinus fontinalis* (Mitchill)
Dolly Varden	*Salvelinus malma* (Walbaum)
Lake trout	*Salvelinus namaycush* (Walbaum)

[1/] From "A List of Common and Scientific Names of Fishes from the United States and Canada," American Fisheries Society Special Publication No. 6, Third Edition, 1970, 150 p.



INTRODUCTION

Many pulp and paper mills in North America are either on or near tidal estuaries or on rivers adjacent to estuaries. The anadromous fish that migrate through these estuaries and rivers are valuable for commercial and sport fishing. Inevitably some of these fish contact mill effluents at some concentration.

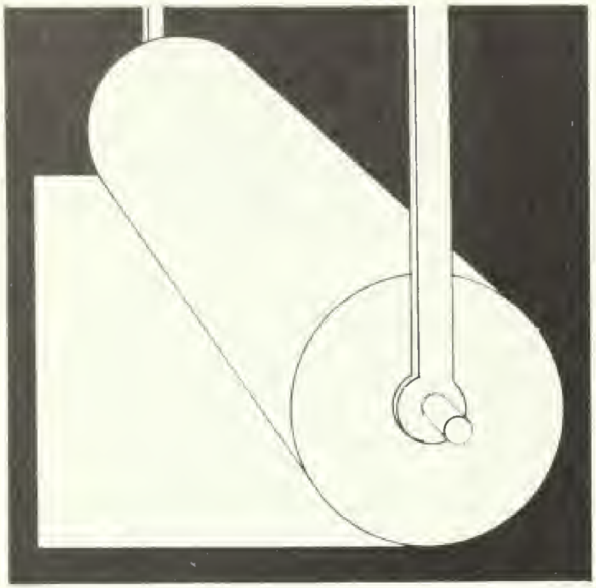
For nearly 50 years, we have known that effluents from pulp and paper mills may be toxic to fish and other aquatic animals. Effluents from both kraft and sulfite mills are complex mixtures that differ greatly in toxicity, depending on many factors. The toxicity of mill effluents results from the combined activity of a number of chemicals, some of which have not been completely identified. In addition to acute toxicity, pulp and paper mill effluents may be harmful to fish and other aquatic animals because of their biological oxygen demand. High concentrations of wood sugars in mill wastes require oxygen during decomposition; hence, as the sugars are stabilized, dissolved oxygen in the receiving water is rapidly depleted. Dissolved oxygen is required by all aquatic animals except anaerobic bacteria.

The difficulty of separating effects of chemical toxicity from effects of biological oxygen demand, and the inability to identify the chemical constituents of effluents, have complicated pollution evaluation studies in the past. The recent development and testing of reproducible bioassay procedures has dramatically changed this situation. Simple, accurate, and sensitive biological assessments are now possible (Walden 1976).

The acute toxicity of various pulp and paper mill effluents is often quite low. Despite their low toxicity, pulp and paper discharges may have a high impact on receiving waters because of the tremendous volumes discharged.

Considerable technological progress in the past decade has reduced harmful effluents. Modern mills that meet Federal and State requirements for pollution abatement differ substantially from the mills that operated 20 or 30 years ago.

Many of the logging camps in Alaska and British Columbia are closely associated with pulp and paper mills because much of the harvested timber goes to the mills. Because of this close association, a discussion of camps and their potential effects on anadromous fish habitat is included in this paper.



PROCESSING MILLS

TOXICITY OF EFFLUENTS

The toxicity of effluents from pulp and paper mills has been studied for many years. Some of this work was on the effects of pulp effluents on salmonid fishes (Dimick and Haydu 1952, Lasater 1953, Williams et al. 1953, Alderdice and Brett 1957, Van Horn 1958, Waldichuk 1960, Howard and Walden 1965, Servizi et al. 1968).

A general review of the environmental effects of pulp and paper wastes has been prepared by Marier (1973). Van Horn (1961, 1971) reviewed the pulp and paper industry as it affects aquatic biology. Walden (1976) published an excellent review on the toxicity of effluents from pulp and paper mills.

Effluents from both kraft and sulfite mills are complex mixtures that differ greatly in toxicity depending on many factors. Because all chemical constituents have not been identified, the effects must be assessed biologically. Several species of fish and many other aquatic organisms have been used for test purposes (Dimick and Haydu 1952, Lasater 1953). Laboratory bioassays have been used to predict toxicity under conditions in natural ecosystems. The definition of reproducible bioassay procedures has been an important step in making bioassays useful (Walden 1976). Simple, accurate, and sensitive bioassays are now possible. Data are converted into toxic units, which may be compared directly, even though bioassay procedures may vary. Maximum accuracy is achieved with 50 percent fish survival. Most toxicity tests require at least 24 hours' exposure time (Walden 1976).

For pulpmill effluents, chemical assays are not feasible. Some toxicants have not yet been identified; consequently, they cannot be assayed chemically. Chemical assays would only be useful if they could be correlated with biological responses.

Because of the low concentration of toxicants in effluents from pulp and paper mills, large amounts of effluent must be used in solutions to be bioassayed. The high biological oxygen demand of these solutions requires oxygenation to maintain fish respiration during the tests (Walden 1976).

EFFLUENTS OF KRAFT MILLS

Reported toxicity of kraft wastes to fish dates back to the work of Ebeling (1931) in Sweden. Many workers since then have confirmed that concentrations of kraft mill effluents needed to kill fish ranged from 10 to 100 percent.

The first studies with salmonids (Dimick and Haydu 1952) demonstrated that sodium hydroxide, methyl mercaptan, sodium sulfide, and hydrogen sulfide were toxic (table 1).

Seven pulpmills were monitored daily for 40 days to determine the amount and duration of effluent toxicity. All sewers in the kraft mills contained toxic chemicals, and substantial daily variation in toxicity was common. Toxicity levels of effluents seldom remained constant more than 12 hours and often varied more frequently (Howard and Walden 1971).

Howard and Walden (1965) studied the toxicity of streams with kraft-process effluents to guppies, Poecilia reticulata (Peters), and sockeye salmon in fresh water at neutral pH. As much as 75 percent of the mortality reported by previous authors was caused by an imbalance in pH. Fish acclimated to increasing concentrations of effluents in a few days. Test fish exposed to gradually increasing effluent could survive concentrations considerably higher than the values demonstrated as lethal in the bioassays. Thus, concentration values related to various rates of mortality, such as LC_{50} (50 percent of the test animals are killed), can be misleading. Length of exposure, other stresses on the fish, pH and temperature of the water, age of the fish, and many other factors can significantly affect pollution concentrations necessary to cause fish mortality.

Effects of kraft effluents on invertebrates indicate that none are more sensitive than juvenile salmonids and some species are much more resistant (Walden 1976).

SULFITE WASTES

Williams et al. (1953) first demonstrated that sulfite waste liquids were acutely toxic to fish. Previous workers had difficulty demonstrating toxicity, other than the effects of heavy oxygen demand. Kondo et al. (1973), working with neutral sulfite semichemical wastes, showed that they were about one-third as toxic as kraft wastes. Toxicity did not diminish in storage as it did with kraft

Table 1--Threshold concentrations (mg/l) of toxicants in kraft mill wastes lethal to salmonid fishes (after Dimick and Haydu 1952)

Chemical	Chinook salmon	Coho salmon	Cutthroat trout
Hydrogen sulfide	0.3	0.7	0.5
Methyl mercaptan	.5	.7	.9
Sodium sulfide	1.8	1.3	1.0
Sodium hydroxide	27	11	10
Sodium carbonate	58	44	33
Sodium sulfate	--	10,000	2,500

wastes. Holland et al. (1960) found no significant difference in toxicity in ammonia-base and calcium-base pulping liquors.

The toxicity to fish of sulfite pulping wastes is well documented, although the difficulty in segregating toxic effects from those of oxygen demand indicates the limited role toxicity alone plays in natural ecosystems (Walden 1976).

Literature on the effects of sulfite wastes on organisms other than fish is scarce. The available evidence shows that bivalves are especially susceptible. Odlaug (1949) showed that concentrations as low as 100 parts per million of spent sulfite liquor reduced the pumping rate of Olympia oysters (*Ostrea lurida* Carpenter) by 8 percent after immediate exposure. Complete cessation of pumping occurred after 15 days. Stein et al. (1959) showed that concentrations of ammonia-base, spent sulfite liquor greater than 55 parts per million affected spawning of oysters, but lower concentrations stimulated activity. Oysters appear to be more sensitive to spent sulfite wastes than any other species tested (Woelke 1967).

SUBLETHAL EFFECTS OF PULPMILL EFFLUENTS

Biologists have long recognized that concentrations approaching lethal amounts of pollutants, as determined in bioassays, are not safe for survival and maintenance of fish stocks (Fry 1971). The results of bioassays are valueless and misleading unless they can be related to concentrations producing no harmful effects to the ecosystem. Stresses are cumulative, and any stress on an organism reduces its ability to withstand other stresses.

The known sublethal effects of pulp and paper effluents are attributable to coniferous fibers, hydrogen sulfide, and nonvolatile soluble toxic substances (Walden 1976). The last group is of major environmental concern.

Walden and Howard (1968) described effects displayed by fish after exposure to lethal concentrations of kraft effluent: loss of schooling, respiratory distress, abnormal gill movements, reluctance to eat, loss of equilibrium, convulsive coughing, excessive mucous production, and finally death.

Jones et al. (1956) showed that some species of salmon avoided regions containing pulpmill waste. Chinook salmon were best able to avoid the waste, coho salmon were less able, and steelhead trout showed no noticeable reaction. Inconsistent results were demonstrated in some other studies, such as those of Dimick et al.

(1957); salmon sometimes avoided concentrations that attracted other test fish.

The ability of fish to swim is affected by pulpmill wastes (Howard 1973, 1975). Howard and Walden (1974) developed techniques to measure swimming; speed and stamina decreased after effluents reached a threshold concentration.

Fish growth may be adversely affected by moderate to high concentrations of kraft mill effluents, but low concentrations stimulated growth (Webb and Brett 1972).

Schaumburg et al. (1967) studied the effects of sublethal concentrations of kraft effluent on fish respiration. They found that stressed fish reversed the flow of water past their gills; this was designated as "coughing." Coughing increased with increasing concentrations of effluents.

Evidence of effects of sublethal concentrations of wastes from pulp and paper mills on organisms other than fish is not extensive. Available data indicate that the threshold at which sublethal concentrations affect invertebrates corresponds roughly to that affecting fish (Walden 1976).

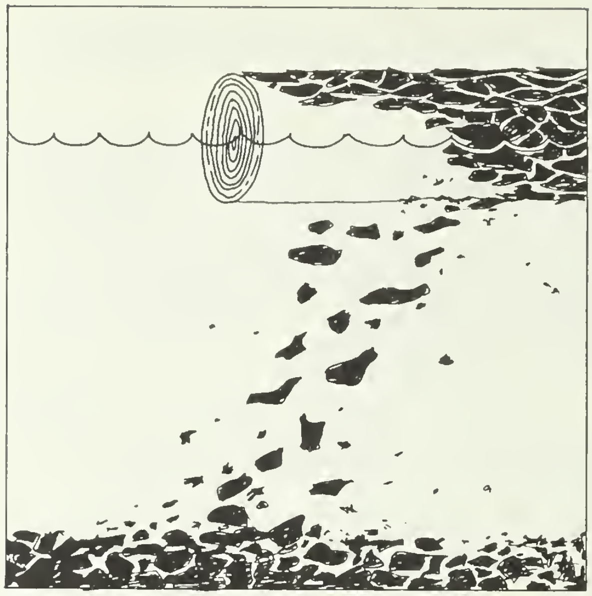
OXYGEN DEMAND

High concentrations of wood sugars in sulfite wastes require oxygen during decomposition. The oxygen requirements for stabilization of the sugars result in a high biological oxygen demand which can result in rapid depletion of dissolved oxygen in the receiving water (Waldichuk 1960).

Kraft mill wastes also contain high concentrations of organic material, but not nearly as much as in sulfite liquor.

Walden (1976) stated that difficulties in segregating toxic effects from those caused by oxygen demand emphasize the limited role toxicity plays in natural situations, compared to problems arising from potential oxygen depletion. Thus, the primary effect of sulfite wastes is apparently to increase biological oxygen demand.

The dissolved oxygen level required to sustain fish varies considerably, because it depends on other factors such as water temperature, salinity, pH, fish species, and other stresses on the fish. Despite efforts to decrease the biological oxygen demand of wastes from pulp and paper mills, the effect of these wastes on dissolved oxygen remains a problem in some receiving waters.



SUSPENDED SETTLEABLE MATERIALS

Bark, chips, and pulp fibers concern fishery biologists and others because they have long-term effects on the aquatic environment. As these materials begin to cover the bottom, the rich fauna often found there is either destroyed or forced to move. Fish that normally feed on or near the bottom also find the area unattractive and move elsewhere. As the organic materials start to decompose and dissolved oxygen in the water is used up, hydrogen sulfide is released. The bottom layer of water, with low dissolved-oxygen levels, may become very thick and, thus, unsuitable for many species of food fish. This is especially true in inlets and other restricted locations where strong tidal flushing does not occur.

Particles of bark, chips, and fibers come mainly from drum and hydraulic barkers, paper machines, and from transferring chips from scows to the mill. Bark also sloughs off logs during raft transport and during storage in holding ponds. Log-transfer sites often contain heavy accumulations of bark and other wood debris (Schaumburg 1973).

Row and Cook (1971) found that most of the toxicity from mechanical pulping effluents was caused by resin acid soaps. Wilson (1975) studied the toxicity of effluents from newsprint operations. Biotreated effluent had no adverse reaction on any of the zooplankton and invertebrates tested.

Raw wood is about half cellulose fibers. Modern mills use settling tanks, filters, and other devices to keep fibers out of receiving waters.

Bark accumulations may contaminate salmon spawning grounds (Servizi et al. 1968). Servizi and his coworkers found that the oxygen demand of bark is great enough and of long enough duration that eggs can be killed. Fine bark particles can also clog the gravel, causing egg mortality. These authors estimated that bark concentrations of 4 percent and more were likely to increase egg-to-fry mortality because of oxygen depletion at incubation velocities of 5 cm/h. Even bark concentrations of 1 percent and greater could retard emergence. Egg mortality increased as bark accumulations increased and water flow decreased.

Even though bark leachates are toxic, studies by Schaumburg (1973) showed that leachates from logs in natural waters had little toxic effect. In a study of woodroom effluents, Howard and Leach (1973) found that softwood species tended to be more toxic than hardwood species.

Leachates from logs also contain wood sugar and other biodegradable materials that exert a large biochemical oxygen demand (Schaumburg 1973). Extracts of spruce (*Picea* sp.) and hemlock (*Tsuga* sp.) bark are also toxic to fish, shrimp (*Pandalus* sp.), and dungeness crab (*Cancer magister* Dana)(Buchanan et al. 1976). Toxic effects on salmon fry were observed as soon as 3 hours after exposure to hemlock bark extracts. After a 96-hour exposure at a concentration of 56 milligrams per liter, 50 percent of the salmon fry were killed. Spruce bark extracts were consistently toxic to all invertebrates tested.

Concentrations of leachates great enough to be toxic are unlikely except in certain locations with little or no tidal flushing, such as log-handling and storage areas.

AIR POLLUTION

Stack emissions from pulp and paper mills contain many chemicals. Some, such as sulfur dioxide (SO_2), can damage plants if concentrated sufficiently and if exposure continues long enough (Faller 1971, Linzon et al. 1972, Carlson 1974).

Sulfur dioxide is a soluble gas readily absorbed by foliage through the stomata. Absorption can also occur through wet leaf surfaces (Thomas et al. 1950). If SO_2 is not removed from the air, it oxidizes to SO_3 and becomes a sulfuric acid mist. This mist is corrosive and can cause lesions on plant tissue.

Confirmation of damage to needles by SO_2 requires that foliage samples be analyzed for sulfur. Histological examination of needles shows a distinctive syndrome unlike that caused by pathogens, drought, or freezing. Several investigators have established that high sulfur dioxide concentrations can injure or kill plants (Thomas et al. 1950, Faller 1971, Linzon et al. 1972, Ratsch 1974).

When mills are located near rivers used by salmon and other anadromous fish, they can affect fish habitat through air pollution that kills riparian vegetation. Several studies have shown the importance of streamside vegetation in reducing stream temperatures, producing logs in the stream for cover, and forming pools (Meehan et al. 1977). Trees along streambanks also harbor insects that drop into streams and are eaten by fish and other aquatic organisms.

The extent and severity of injury to riparian vegetation resulting from pulpmills depend on wind patterns and surrounding terrain as well as the amount of pollutants emitted from the mill. The presence of a pulpmill does not guarantee that nearby trees will die. If emissions are not great and air currents provide mixing, SO_2 concentrations may not be high enough to cause damage to trees or other plants (Ratsch 1974).

CAMPS

Except in Alaska and British Columbia, logging camps are nearly nonexistent in North America. A few camps occur in other places, but they are usually not permanent.

About 60 logging companies operate in southeast Alaska (Pease 1974). Some have floating camps that are towed from one anchorage to another but most are land based. They range in size from a one-family operation to a community of 500 people or more. Camps are usually located in protected harbors that serve as log-storage and transfer sites.

In the past, few regulations controlled logging camps. Some activities could have affected anadromous fish, but we have no record of it. Logging camps are now regulated by the Environmental Protection Agency, the USDA Forest Service, and the States. In Alaska, the State Department of Environmental Conservation also has authority. Logging camp sewage or solid wastes are unlikely to affect fish habitat adversely if regulations of these agencies are complied with. The Environmental Protection Agency requires secondary sewage treatment. Chlorinated wastewater could be toxic to fish if concentrations of chlorine were high.

Logging camps used to leave rusting cables, junked machinery, bands from log bundles, spilled fuel, and other debris on or near their sites when a camp was abandoned. No studies document the effects of these materials on fish habitat, however. Present regulations require that the sites be cleaned before the camp is moved.

GRAVEL REMOVAL

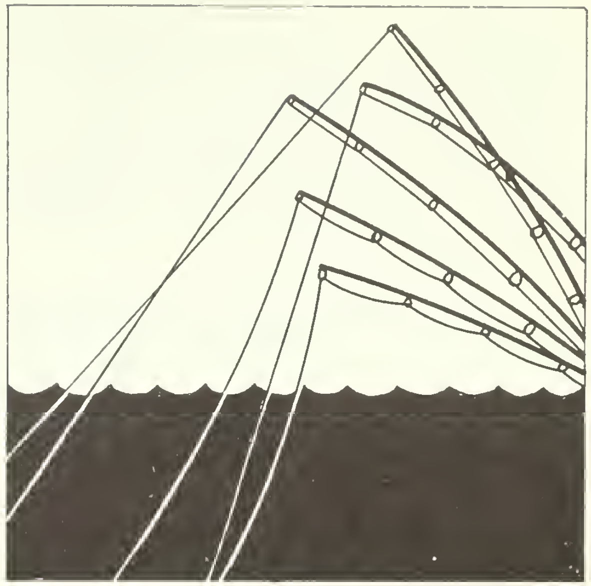
Large amounts of gravel are needed for building logging roads and developing campsites. Some locations have no source of gravel nearby, other than streambeds. Although gravel has been taken from streams in the past, this practice was probably never common and it will no doubt become less common.

Two examples of gravel removal from streambeds have been documented in Alaska. Sheridan reported on the removal of gravel from a stream on Baranof Island near Sitka, Alaska.[2/] Road construction and logging were started in the Rodman Creek watershed in 1960 and completed in 1965. Surveys showed that the stream and alluvial flood plain contained the only gravel nearby; 64,000 cubic yards of gravel were taken from 16 borrow pits located on the tideflats, flood plain, and in the stream. Pink and chum salmon spawned in the intertidal area and up to 5 miles upstream. The Alaska Department of Fish and Game had records of escapement before gravel removal and continued these surveys during and after the gravel was removed. The borrow pits filled with gravel in 4 years, no significant changes were observed in streambed gradient, and the pits accelerated bank cutting in their vicinity, causing several trees to fall into the stream and a high intermittent sediment load. The pit-filling probably increased bedload movement and likely increased the instability of spawning beds upstream. Salmon escapement showed no

[2/] Unpublished paper, "Effects of gravel removal on a salmon spawning stream," by W. L. Sheridan. USDA For. Serv., 26 p. On file, Forestry Sciences Laboratory, Juneau, Alaska, 1967.

decrease, even though a short-term decrease in survival of salmon embryos could have occurred because of increased sedimentation. Sheridan cautioned that gravel should be removed from streams only if no other source of gravel is available and the value of timber far exceeds the potential damage to salmon habitat.

During World War II, large amounts of gravel were removed from four salmon streams near the Kodiak Naval Station (McVey 1959). Sections of the streambed were removed to depths of 20 feet. The fish-producing potential was reduced in two streams because the tailings from washing and screening reduced the average size of stream gravel, resulting in instability. In the other two streams, bottom materials broke up and were washed downstream. As a result, streamflow was limited to subterranean seepage during low water flows, and several miles of excellent spawning grounds became inaccessible to spawning fish. By 1958, the gravel of only one of the two streams showed signs of stabilizing.



FISHING BY RESIDENTS

Logging camps congregate people in remote areas of southeast Alaska and British Columbia. The camps are often near highly productive stream and estuarine fisheries. This combination of people and resources results in heavy use.

Some biologists believe that logging camps are responsible for unusually heavy fishing pressure in some streams. Depletion of runs has been mentioned, but quantitative data are lacking. Species such as steelhead trout would be especially vulnerable, because the runs are small in some streams. The Alaska Department of Fish and Game has estimated that sport harvest in Rodman Creek, Baranof Island, took over 60 percent of the mature Dolly Varden char in 1963, based on tag returns. This pressure was mainly from nearby logging camps.[3/]

[3/] Data on file, Forestry Sciences Laboratory, Juneau, Alaska.

The Alaska Department of Fish and Game is now conducting a statewide sport fishing survey. Information will be received from high-quality watersheds, including those near logging camps, so sport fishing harvests from logging camps can be estimated.

If anglers all carry proper licenses and observe bag limits, the logging camps only serve to distribute and congregate people, so it may be misleading to view camps as detrimental to the fisheries resource.

OTHER EFFECTS OF CAMPS

Some logging camps probably have affected the local fisheries by sewage pollution, water diversion, oil and lubricant spills, and gravel removal, although the effects of these activities have not been documented.

In light of the detailed State and Federal water and air-quality standards, logging camps are unlikely to have any appreciable effect on fish habitat now or in the future. Logging camps may be viewed as small communities, subject to the same regulations as any other community. If environmental degradation occurs it is because State and Federal regulations are being violated.

SUMMARY AND CONCLUSIONS

Pulp and paper mills release enormous amounts of effluents daily into receiving waters. The toxicity of these wastes varies widely and is dependent on factors such as chemical processes used, waste recovery, and biological oxygen demand caused by decomposition of sugars in the effluents.

Until recently, assessing the harmful effects of mill wastes was difficult because the chemical constituents are complex, and some remain unidentified. The relation between the concentration of many toxic constituents and biological activity has not been established. In addition, separating chemical toxicity from biological oxygen demand is often difficult. As a result chemical assays cannot be used.

Laboratory and field studies have accumulated the data needed to design accurate and sensitive acute lethal bioassays for effluents from pulp and paper mills. These bioassays have been used to identify threshholds of effluent toxicity for several aquatic animals, including salmonid fishes. This work has demonstrated that the previous history of test animals is very important. Fish and other aquatic animals can be conditioned to withstand increasing levels of pollutants to a point. Stresses tend to be cumulative, however, and such factors as water temperature and pH can compound the effects of other stresses. Despite some shortcomings, recent research on biological assessment has resulted in the development of tables showing concentrations of effluents associated with effects on various organisms. Threshold concentrations of effluents from paper mills have been based on extensive technical data; this work has been reviewed by Walden (1976).

The acute lethal bioassay is now well established for measuring toxicity of industrial pollution. Using such bioassays to determine safe levels of effluent in the environment is risky, however. Each biological system is unique; plants and animals in the system are subjected to various stresses. The amount and duration of these stresses determine the animal's ability to withstand the added stress of mill pollution. What is needed is a sublethal bioassay, sensitive enough to detect changes in the natural environment as they relate to biological requirements of the animals.

Little information is available on the effects of logging camps on anadromous fish habitat. Because camps are often near productive fish habitat, however, they are potentially hazardous. Present regulations pertaining to camps and associated activities appear adequate to prevent appreciable damage.

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